

BULLETIN

of the

American Association of Petroleum Geologists

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THE BULLETIN is published by the Association on the 15th of each month.

EDITORIAL AND PUBLICATION OFFICE AND ASSOCIATION HEADQUARTERS, 708 Wright Building, 115 and 117 West Third Street, Tulsa, Oklahoma. Post Office, Box 979, Tulsa 1.

BRITISH AGENT: Thomas Murby & Co., 40 Museum Street, London, W. C. 1.

SUBSCRIPTION PRICE to non-members is \$15 per year (separate numbers, \$1.50), prepaid to addresses in the United States; outside the United States, \$15.40.

CLAIMS FOR NON-RECEIPT must be sent within 3 months of date of publication, to be filled gratis.

BACK NUMBERS, if available, may be ordered from Headquarters. Price list on request.

	Mem.	Non-Mem.
Cloth-bound Bulletin, Vols. 12 (1928)-15 (1931) incl., each	\$5.00	\$ 6.00
Vols. 26 (1942), and 29 (1945), each	4.00	17.00

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 BOX 979, TULSA 1, OKLAHOMA

Entered as second-class matter at the Post Office at Tulsa, Oklahoma, and at the Post Office at Menasha, Wisconsin, under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized March 9, 1913.

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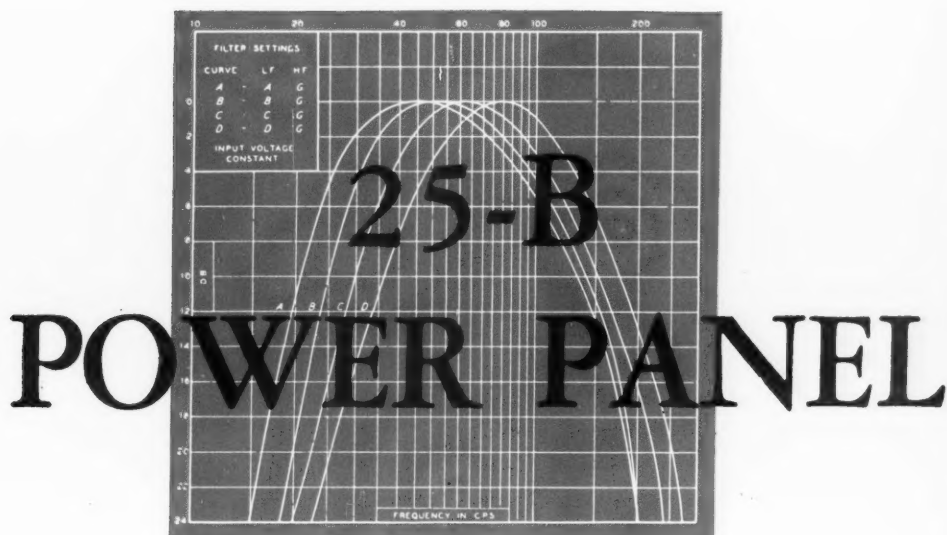
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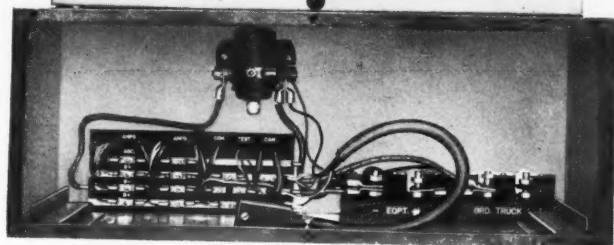
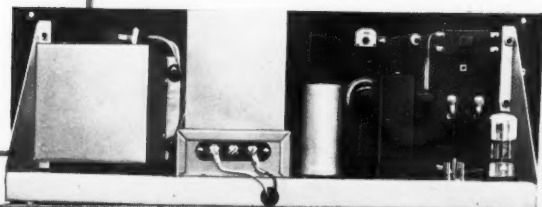
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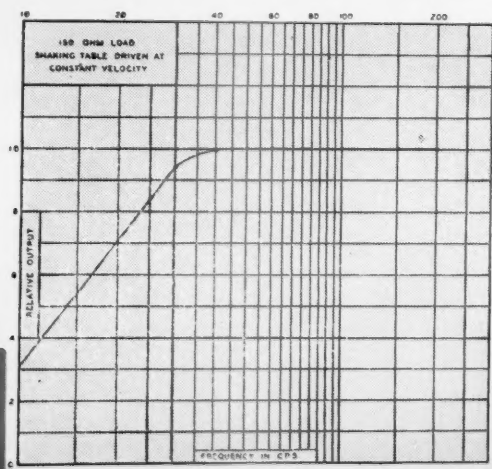
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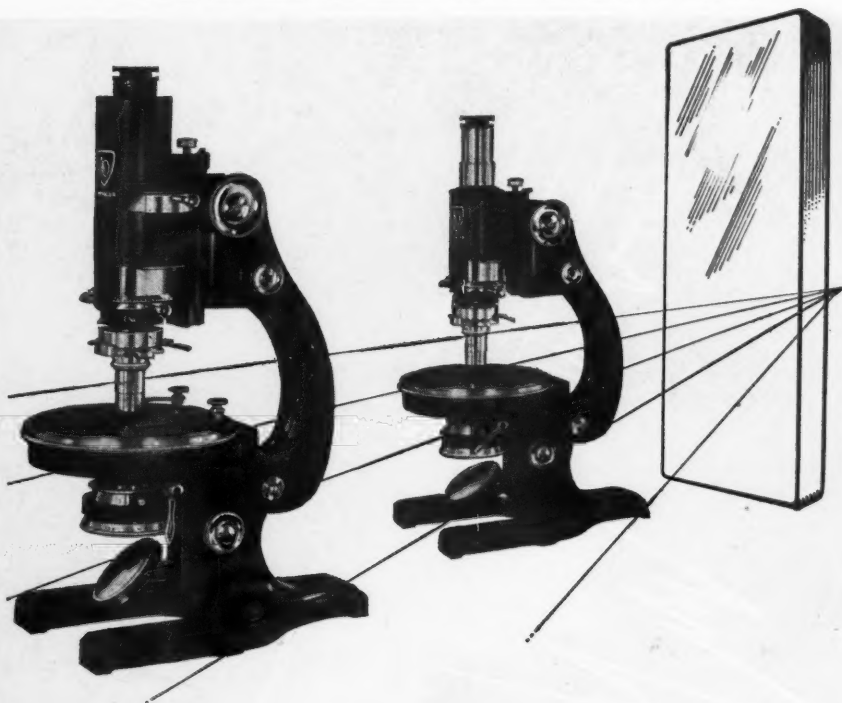
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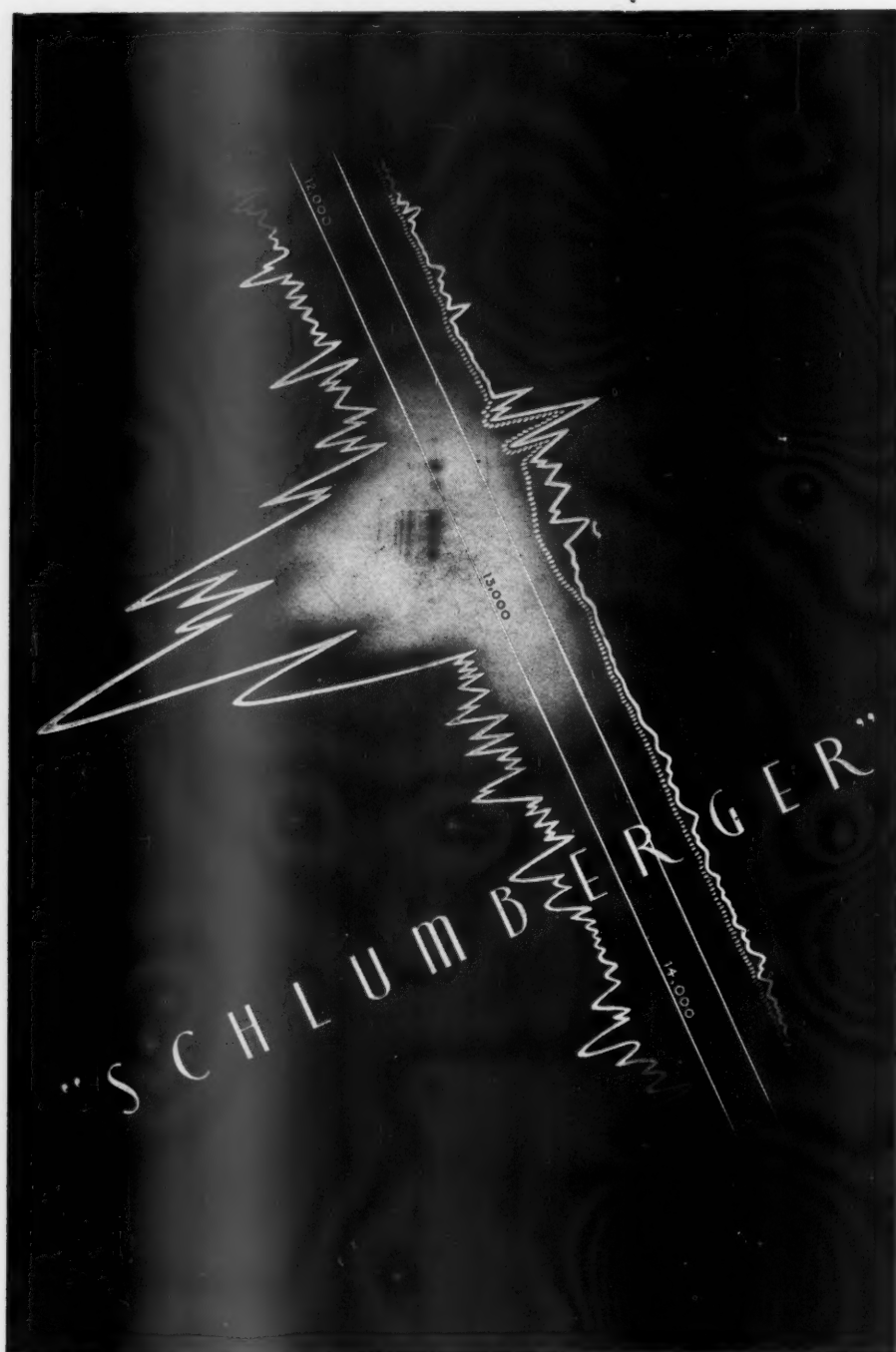
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BULLETIN
of the
**AMERICAN ASSOCIATION OF
PETROLEUM GEOLOGISTS**

FEBRUARY, 1946

GEOLOGY OF KATY FIELD, WALLER, HARRIS, AND
FORT BEND COUNTIES, TEXAS¹

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LAKE,⁶ RAY C. LEWIS,⁷ P. H. O'BANNON,⁸ S. R. SELF,⁹ AND C. A. WARNER¹⁰
Houston, Texas

ABSTRACT

The Katy field, located in Waller, Harris, and Fort Bend counties, Texas, and 30 miles northwest of the industrial area of Houston, was discovered in the early part of 1935. Development has shown the productive area to be between 29,000 and 30,000 acres and probably the most important gas-condensate reserve in the United States. The structure is a broad domal anticline unbroken by faulting. Gas condensate, and oil are produced between the depths of 6,250 feet and 7,450 feet from sands in the Yegua formation. The 1,200-foot producing section is segregated into six productive or potentially productive reservoirs each with separate fluid levels and reservoir characteristics. On July 1, 1945, gas and condensate were being produced from the second, third, fourth, and fifth zone reservoirs and oil was being produced from one or more sand members in the first and second zones. On this date 85 wells had been drilled on the structure, of which 44 were completed for gas production or return, 29 for oil production, and the remaining 12 were dry holes.

The current, July 1, 1945, average daily allowable from the field is approximately 1,000 barrels of oil, 14,000 barrels of condensate, and 450 million cubic feet of gas of which approximately 85 per cent is being returned to and stored in the reservoir.

INTRODUCTION

Discovery of the Katy field in 1935, the largest gas-condensate reserve in the Coastal Province, added a new type of development to the coastal history. Katy

¹ Manuscript received, November 17, 1945. The managements of the companies and the operators have graciously granted their permission for the publication of this paper; for their cooperation and courtesy, the writers extend thanks and acknowledge their appreciation.

² Geologist, Sun Oil Company.

³ Geologist, independent (formerly with the Union Producing Company).

⁴ Geologist, Sinclair Prairie Oil Company.

⁵ Geologist, Stanolind Oil and Gas Company.

⁶ Geologist, Tide Water Associated Oil Company.

⁷ Geologist, Houston Oil Company of Texas (formerly with the Stanolind Oil and Gas Company).

⁸ Geologist, Humble Oil and Refining Company.

⁹ Geologist, Amerada Petroleum Corporation.

¹⁰ Geologist, Houston Oil Company of Texas.



FIG. 1.—Regional map showing location of Katy field.

was the site for the installation of one of the first cycling plants for the recovery of liquid hydrocarbons and storing the residue gas in the original reservoirs for future sale.

The Katy field, in addition to ranking first in productive area and to being the largest single gas-condensate reserve known, has other features that are not attributable to any other coastal field. Its structural closure is thought to be due to the settling of the formations representing the flanks of the field as a result of the removal of the underlying salt to form the neighboring shallow piercement salt domes. The conspicuous absence of faulting may or may not be a result of the abnormal structural origin. This paper summarizes all data available at this time and the structural features are displayed by several structural maps and geological cross sections of the field. The writers have attempted to discuss each phase of the structure and its development in sufficient detail and without repetition to acquaint the reader with all pertinent data.

A reference map with well tabulations (Fig. 2 and Table I) has been prepared to aid the reader and to clarify the paper. In this tabulation the two Katy Gas Field Units are referred to as K.G.F.U. I. and K.G.F.U. II.

LOCATION

The Katy field is located in Waller, Harris, and Fort Bend counties, Texas, with the larger part of the field in the extreme southeast corner of Waller County (Fig. 1). The town of Katy, from which it is named, is located in the southeastern part of the field, and is approximately 30 miles west of the city of Houston in Harris County. The field is served by the Missouri, Kansas, and Texas Railroad from which the town of Katy derives its named.

HISTORY AND DEVELOPMENT

In 1934, the owners of certain oil and gas leases in the Katy area agreed to unitize their interests, and drill an exploratory test. Most of the leases in H. & T. C. R. R. Secs. 99, 100, 109, and 110 were included in the unitized block which was generally referred to as the "four-section unit." The operators entered into this agreement on an acreage basis and Stanolind Oil and Gas Company was selected to be the operator.

The initial test, Thorp No. 1 (Katy Gas Field Unit I, No. 3), was located near the southeast corner of H. & T. C. R. R. Sec. 100, and became the discovery well for the Katy field. Thorp No. 1 was drilled to the total depth of 7,647 feet, penetrating a total of 274 feet of net effective gas-condensate sand in the Yegua formation between the depths of 6,378 and 7,409 feet. Completion was made in February, 1935, by setting screen opposite sands from 7,109 to 7,139 feet, and 7,351 to 7,401 feet. One test flowed at a daily rate of 3,180 MCF¹¹ of gas with large quantities of colorless condensate through $\frac{1}{4}$ -inch choke. After being tested for several days on varying chokes the hole was filled with heavy drilling mud and tempo-

¹¹ MCF = 1,000 cubic feet.

TABLE I
KATY FIELD WELLS

Well Reference Number	Operator	Well Number	Lease	Eleva- tion (Feet)	Total Depth (Feet)
1	Stanolind Oil & Gas Co.	3	G. Pattison	188	7,540
2	Stanolind Amerada	1	M. Maynor	187	6,713
3	Stanolind Oil & Gas Co.	1	H. Muske	186	7,400
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5	Sun Oil Co.	1	H. Muske	190	7,401
6	K.G.F.U. II	14	A. F. Smock	190	7,446
7	Stanolind Amerada	1	G. Pattison	190	8,000
8	Humble Oil & Refg. Co.	2-B	H. Hebert	188	6,868
9	Humble Oil & Refg. Co.	1-B	H. Hebert	186	7,185
10	Humble Oil & Refg. Co.	1-B	E. C. Stockdick	187	6,877
11	Tide Water Assoc. Oil Co.	1	E. C. Stockdick	190	7,309
12	Stanolind Amerada	2	G. Pattison	193	7,400
13	Humble Oil & Refg. Co.	3-B	C. A. Pontious	193	6,878
14	Humble Oil & Refg. Co.	1-B	C. A. Pontious	194	7,450
15	Stanolind Amerada	4	G. Pattison	192	7,259
16	Humble Oil & Refg. Co.	3-B	E. C. Stockdick	189	6,879
17	K.G.F.U. II	23	E. C. Stockdick	189	7,375
18	Humble Oil & Refg. Co.	1-C	H. Hebert	189	6,878
19	Humble Oil & Refg. Co.	1	C. H. Stockdick	187	6,877
20	K.G.F.U. II	21	C. H. Stockdick	187	7,400
21	Humble Oil & Refg. Co.	2-B	E. C. Stockdick	188	6,877
22	K.G.F.U. II	19	G. Pattison	191	7,400
23	Humble Oil & Refg. Co.	2-B	C. A. Pontious	193	6,887
24	K.G.F.U. II	18	G. Pattison	191	7,415
25	Humble Oil & Refg. Co.	1-B	T. B. Tucker	187	6,883
26	Humble Oil & Refg. Co.	1-B	C. H. & E. G. Stockdick	188	6,878
27	Humble Oil & Refg. Co.	1-B	H. L. Stelzig	187	6,880
28	Sun Oil Co.	1-A	J. M. Stewart	186	6,980
29	Humble Oil & Refg. Co.	1-B	J. M. Stewart	185	6,880
30	Humble Oil & Refg. Co.	1-B	E. A. Showers	182	6,874
31	K.G.F.U. II	20	G. C. Daniels	180	7,375
32	Humble Oil & Refg. Co.	1-B	A. T. Jones	180	6,870
33	Kirby Petroleum Co.	1	D. W. Beckwith	181	7,340
34	Kirby Petroleum Co.	2	D. W. Beckwith	184	6,658
35	Humble Oil & Refg. Co.	1-B	P. C. Cullom	184	6,865
36	Humble Oil & Refg. Co.	3-B	T. B. Tucker	185	6,878
37	K.G.F.U. II	22	H. Laas	185	7,335
38	Humble Oil & Refg. Co.	2-B	T. B. Tucker	184	6,871
39	K.G.F.U. II	24	T. B. Tucker	183	7,345
40	Humble Oil & Refg. Co.	2-B	P. C. Cullom	182	6,875
41	C. V. Hagen	1	A. T. Jones	180	6,635
42	Humble Oil & Refg. Co.	2-B	R. F. Woods	177	7,350
43	K.G.F.U. II	17	R. F. Woods "C"	176	7,331
44	Humble Oil & Refg. Co.	1	B. F. Beckendorf	171	7,410
45	Humble Oil & Refg. Co.	3-B	R. F. Woods	177	6,869
46	K.F.G.U. II	3	American Rice Milling Co. "D"	183	7,340
47	Humble Oil & Refg. Co.	1-D	American Rice Milling	187	7,925
48	K.F.G.U. II	2	American Rice Milling Co. "C"	181	7,820
49	K.G.F.U. II	4	M. A. Morrison	178	7,450
50	K.G.F.U. II	8	R. F. Woods	176	7,500
51	Humble Oil & Refg. Co.	1-B	L. L. Scharff	172	6,874
52	K.G.F.U. II	1	L. L. Scharff	170	7,600
53	Humble Oil & Refg. Co.	3-C	B. H. Alexander	171	6,870
54	K.F.G.U. II	5	B. H. Alexander	167	7,315
55	K.G.F.U. I	18	Jones & Campbell	173	7,313
56	K.F.G.U. I	1	L. S. Loucks	180	7,541
57	K.G.F.U. I	17	C. F. Schilpf	177	7,270
58	K.G.F.U. II	9	C. K. Weinman	170	7,320
59	Sun Oil Co.	1	M. Mansell	160	7,775

TABLE I—Continued

Well Reference Number	Operator	Well Number	Lease	Eleva- tion (Feet)	Total Depth (Feet)
60	K.G.F.U. I	16	V. Bourdette	176	7,415
61	K.G.F.U. I	4	W. B. & M. P. Cohee	176	7,403
62	K.G.F.U. I	3	C. W. Thorp	176	7,647
63	K.G.F.U. I	2	American Rice Milling Co. "B"	177	7,318
64	K.G.F.U. I	8	W. E. Freeman	173	11,004
65	K.G.F.U. I	9	J. J. Sweeney	173	7,500
66	K.G.F.U. II	7	W. M. Wiggins	159	7,315
67	K.G.F.U. I	20	Ben Taub	163	7,388
68	K.G.F.U. I	11	A. W. Robertson	170	7,500
69	K.G.F.U. I	10	W. M. Hargraves	171	7,500
70	K.G.F.U. I	7	C. J. McCarty & Williamson	172	7,300
71	K.G.F.U. I	6	Security Trust Co.	170	7,542
72	K.G.F.U. I	5	C. E. Seymour	173	7,400
73	K.G.F.U. II	11	J. T. Crysap	170	7,353
74	K.G.F.U. I	19	J. J. Stoutenborough	170	7,315
75	K.G.F.U. I	13	H. M. Alsup	170	7,386
76	K.G.M.U. I	12	F. Young	170	7,500
77	K.G.F.U. I	14	F. Young	162	7,292
78	K.G.F.U. II	15	A. K. Robertson	154	7,304
79	K.G.F.U. II	12	J. Cope	159	7,502
80	K.G.F.U. I	15	A. C. Peck	165	7,306
81	K.G.F.U. II	10	A. L. Short	168	7,315
82	K.G.F.U. II	6	Ida Cleary	164	7,315
83	K.G.F.U. II	13	John Alt	158	7,317
84	K.G.F.U. II	16	G. J. Bartlett	146	7,296
85	Northern Ordnance Corp.	1	W. J. Morrow	140	7,617

rarily shut in. After sufficient information had been obtained from additional drilling and testing to segregate the various sands into the six respective reservoir groups, it was found that the screen from 7,109 to 7,139 feet was opposite the top sand member of the fourth sand group and the screen from 7,351 to 7,401 feet was opposite the fifth sand. Before the well was produced a packer was set between the two screen settings and the well dually completed from the fourth and fifth sand reservoirs.

It was recognized that an exceptional thickness of gas-condensate sand was present in the Katy field but its potential value was not realized until the advent of cycling and it was almost a decade before the productive limits were defined and the gas-condensate production of the field fully developed.

The future development of the field, following the initial completion, did not seem encouraging as there was no market or prospect of an immediate market for the gas. Operators of the four-section unit were not inclined to continue drilling gas wells which would have to be shut in for lack of an outlet; hence, it was more than 2 years before the second well was drilled. This well, Hargraves No. 1 (K.G.F.U. I No. 10), was located near the center of the SE $\frac{1}{4}$ of H. & T. C. R. R. Sec. 110, more than a mile southeast of the discovery. This test encountered the Yegua sands in a slightly higher position than did the discovery well. Hargraves No. 1 was completed in the fourth sand reservoir as a gas-condensate producer, during May, 1937. Neither of these wells indicated the presence of oil in any of the sands, but it was realized that oil could be present in some of the sands at lower

structural positions. This possibility was not considered sufficient to warrant further drilling.

Additional development was initiated on the four-section unit and adjoining tracts when a market for the gas was secured during 1938. Six wells were completed during 1938, three during 1939, and two during 1941. Gas was first sold commercially from the field in December, 1938.

In the early stages of development it was known that large quantities of valuable liquid hydrocarbons were present in the six reservoirs and a method for their extraction was the subject of much discussion. By the middle of May, 1941, thirteen gas-condensate wells were completed in the field and the proved productive area was in excess of 11,000 acres. Pursuant to the Civil Statutes of Texas, the thirteen operators owning acreage within the estimated productive area agreed to pool their gas interests and construct a cycling plant for the recovery of the liquid hydrocarbons. Katy Gas Field Unit I was formed and a plant was designed to process approximately 200 million cubic feet of gas daily. Construction was commenced in the early part of 1942 and cycling began on January 1, 1943.

Wells drilled during 1942 revealed that the unitized area would cover less than half of the field. The Stanolind Oil and Gas Company-Amerada Petroleum Corporation's Pattison No. 1 gave the field a major extension 3 miles north of the boundary of the unit. It was completed in the second member of the first zone as the first oil well in the field. Shortly thereafter, the Humble Oil and Refining Company's Hebert No. 1, located $\frac{3}{4}$ mile east of Pattison No. 1, was completed as an oil well in the second zone. By the middle of 1943, the gas productive limits had been extended beyond the unitized area more than 3 miles north, as much as a mile east, and $1\frac{1}{2}$ miles south.

The increase of the productive area by more than two and one-half times the original estimate gave rise to problems of properly cycling the reservoir and allocating to the owners of the leases outside of the pooled area an equitable share in the market outlet. After many conferences the operators of the cycling plant agreed to double its original capacity and permit each operator or individual having an interest in gas rights within the extended productive outline to share in its ownership. The enlarged plant went into operation during the latter part of 1944.

Drilling units of approximately 800 acres were formed in compliance with the requirements of the Petroleum Administration for War, and in accordance with the Civil Statutes of Texas. These units were outside the original units and were linked together to form Katy Gas Field Unit II. Exploratory drilling proceeded in this new unit.

During the latter part of 1944 development for gas-condensate production was completed, twenty wells having been completed in K.G.F.U. I and twenty-four in K.G.F.U. II. Most of the gas completions were in the fourth sand, the reservoir currently being cycled. Gas from wells completed in the fifth sand reservoir is being used for plant fuel and sold for industrial use. Five of the gas wells in K.G.F.U. I and eight in K.G.F.U. II are, or will be, used for gas return.

PHYSIOGRAPHY

The Katy field may be described as an area with a flat, monotonous topography. From its southern extremity to its northern limits, the elevation increases uniformly from 140 to 200 feet above sea-level. The flatness of the terrane is unbroken by relief of any prominence.

East and west forks of Buffalo Bayou, muddy streams of low gradient, drain the southern and southeastern part of the field and unite one mile southwest of the town of Katy to form the main stream. This stream flows southeastward for 5 miles, at which point it veers eastward, and continues in that direction to its mouth.

Near the northern limits of the field, Cypress Creek has its source. This stream flows eastward in Waller County, bears northeastward in Harris County, and eventually empties into the San Jacinto River. The southwest flank is drained by the headwaters of Brookshire Creek.

STRATIGRAPHY¹²

The known stratigraphy of the Katy field includes a vertical section of 11,004 feet, ranging from the Lissie formation (Pleistocene) to the Wilcox group (Eocene). The contacts and lithological description of the intervening formations are based on a study of logs, electrical surveys, and well cores and cuttings.

Lissie.—Exposures in the Katy field are recognized as the Lissie formation, Pleistocene in age, and are composed of loose deposits of light tan-colored sands and sandy clays. Samples from the Stanolind's Thorp No. 1 (K.G.F.U. I No. 3) showed sand with some fine gravel to 300 feet, leading to the assumption that the Lissie is a mantle approximately 300 feet thick over the field.

Willis.—The Willis formation, Pliocene in age, underlying the Lissie unconformably, has a thickness of approximately 100 feet between the depths of 300 and 400 feet. Coarser gravel, calcareous clay, and the presence of lime nodules differentiate it from the Lissie.

Fleming (Lagarto and Oakville) (undifferentiated).—In the Katy field the Fleming group, underlying the Willis and overlying the Catahoula, is represented by a predominantly clay section approximately 1,550 feet in thickness, extending to approximately 1,950 feet in depth. Within this interval, there are interbedded sand bodies that range in texture from friable fine-grained to coarse-grained gravelly sandstones, some of which are slightly calcareous.

Electrical logs in the field show the sand bodies as having low self-potential and high resistivity, indicating their content to be fresh water while the clays have the ordinary electrical-log characteristics.

Catahoula.—The Catahoula formation includes the section underlying unconformably the Fleming group previously described and overlying the Anahuac formation. This formation, extending from approximately 1,950 feet to 2,800 feet, is made up of pink and green calcareous shales with interbedded sand bodies.

¹² R. L. Beckelhymer, "Stratigraphy of Waller and Harris Counties, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30, No. 1 (January, 1946), pp. 52-62.

Anahuac.—The Anahuac formation, represented by a thinning updip phase of marine sediments, covers an interval of 120 feet, from 2,800 to 2,920 feet, and is characterized by the presence of marine fossils.

The shales in the Anahuac formation are greenish in color and interbedded with thin sand bodies. Electrical logs show the formation as having characteristic features, making it easily recognizable and suitable for correlative purposes.

Frio.—The formation from 2,920 to approximately 4,550 feet, designated Frio, includes the section underlying the Anahuac and overlying the Vicksburg. The section is composed chiefly of sticky, calcareous, blue and green clays and shales.

Electrical surveys depict a shale section with some sandy phases. Near the base, sand bodies become somewhat more numerous.

Vicksburg (Oligocene).—Underlying the Frio is the Vicksburg formation with a thickness of 450 feet. The top is marked by the first appearance of the *Textularia warreni*.

Electrical surveys show a definite pattern with thin sands in the upper part; the lower part is predominantly shale with a sand near the base just above the Jackson.

Jackson (Eocene).—The Jackson group includes the 1,200 feet of section found between the depths of 5,000 and 6,200 feet, which underlies the Vicksburg and overlies the Yegua. Three well defined formations are recognized in the Jackson: the Whitsett, the McElroy, and the Caddell.

The Whitsett, the uppermost formation, has an average thickness of 250 feet in the field. The top is marked by the first appearance of the foraminifer, *Marginulina cocoensis*. Drillers log this section as shale and sticky shale; their interpretation is borne out by the uniform shale pattern exhibited on electrical surveys.

The McElroy formation is 650 feet thick and is characterized by the presence of the diagnostic foraminifer, *Textularia hockleyensis*. Lithologically, and by electrical surveys, there is little variation between the Whitsett and the McElroy. The same shale pattern of the electrical surveys continues and the same description applies to the penetrated formation.

The lower 270 feet of the Jackson has been ascribed to the Caddell formation with *Textularia dibollensis* as the diagnostic foraminifer. Shales continue nearly to the base where a marly member (Moodys Branch) appears in this formation.

Yegua (Claiborne-Eocene).—The Yegua formation as used herein includes all the section between the overlying Jackson and the underlying Cook Mountain (Crockett). In the Katy field, it occurs within the interval between 6,150 and 7,500 feet, and has a thickness of 1,350 feet.

The upper 250 feet of the Yegua is almost universally called the Cockfield. It is within this zone, near the top, that the first gas-bearing sand is encountered. By common usage, the sand in this interval has been given the name "Cockfield sand" and this term is used throughout its discussion in this paper.

Below the Cockfield is found a series of sands and shales having a thickness of 1,130 feet. The sands within this interval in general are blanket sands, and have

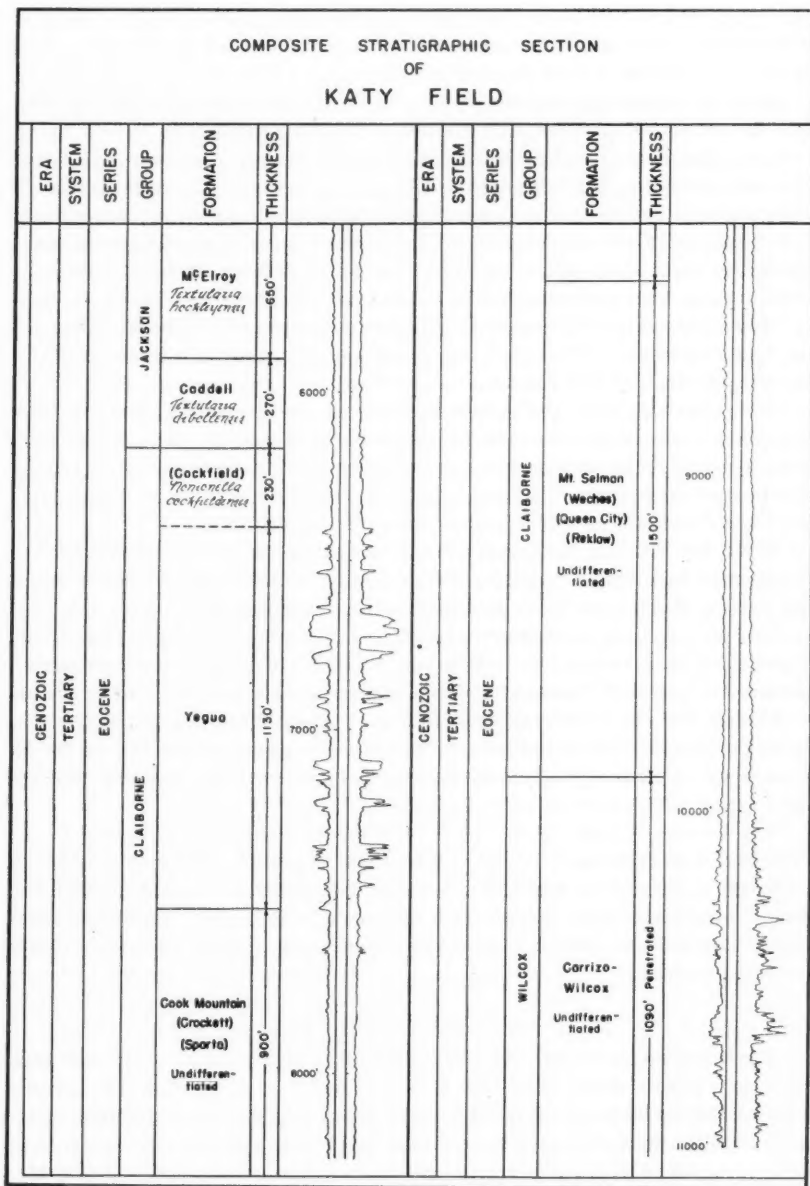


FIG. 3B.—Composite stratigraphic section of Katy field.

been grouped into five zones, based on reservoir levels. The combined thickness of the sands (exclusive of the Cockfield) is in excess of 300 feet. From well to well, there are variations in sand deposition.

Since the producing zones are within the Yegua, the various sands have been used for correlative purposes and in constructing structural maps.

Cook Mountain (Crockett and Sparta undifferentiated) (Claiborne-Eocene).—The next succeeding formation in the Claiborne group is the Cook Mountain. It is composed of two members, Crockett and Sparta sand, and is used to designate only those beds above the Weches and below the Yegua. In the Katy field, since the Sparta sand or its equivalent is not recognizable from electrical survey or well cuttings, the two formations have not been differentiated.

Mount Selman (undifferentiated) (Claiborne-Eocene).—The Mount Selman is the lowest formation of the Claiborne group and is composed of three members: Weches, Queen City and Reklaw.

The glauconitic shale bed between the Sparta and Queen City sands, or their equivalents, is ascribed to the Weches formation. Where the Weches is encountered at considerable depth as it is in the Katy field (8,400 feet), the overlying Sparta sand is not present, having "shaled out" and the top of the Weches, like the Cook Mountain, is determined by use of faunal markers.

Below the Weches, the Queen City sand, that is present on the surface, has disappeared and is represented by a shale section, which continues to the top of the Carrizo-Wilcox, the lower part presumably being Reklaw.

The only well to have penetrated these lower Claiborne formations is the Stanolind *et al.* Freeman No. 1 (K.G.F.U. I No. 8). This well shows an over-all thickness of 1,500 feet from the top of the Weches to the top of the Carrizo-Wilcox.

Carrizo-Wilcox (undifferentiated) (Eocene).—There has been some controversy as to whether the Carrizo belongs to the Claiborne group or the Wilcox group. Since they are lithologically and faunally indivisible, this far down the dip, the Carrizo is incorporated with the Wilcox.

The Carrizo-Wilcox, by electrical survey, was reached at 9,915 feet in the Stanolind *et al.* Freeman No. 1 (K.G.F.U. I No. 8), which, after drilling through 1,089 feet of this section, was still in it at the total depth of 11,004 feet. This section is composed of hard to very hard, micaceous shales, sandy shales, and sandstones with laminae of lignite. These sands have low porosity and permeability in the Katy field.

SUBSURFACE STRUCTURE

The subsurface structure of the Katy field may be described as an ovate anticline, or elongate dome. The apex is located in the south part of the producing area and the long axis strikes N. 10° W., with a long flat nose extending northward from the apex. Although located in a trend where complex structural conditions are common, this field is exceptional for its structural simplicity. The field is extremely regular and is free of faults.

Structural maps have been constructed on the Cockfield sand and on the tops of the other five productive zones. Those on the Cockfield sand, first, third, and fifth zones, are on the sand tops and do not necessarily represent true structural pictures. By using datum planes that are stratigraphically equivalent, regardless of sand development, locally anomalous conditions have been eliminated from the contour maps of the second and fourth zones, and true structure is portrayed.

The productive closure shown by the six structural maps varies from 105 feet for the fifth zone to 295 feet for the second zone, and the greatest total structural closure is in excess of 320 feet.

The Katy structure does not appear to be due to uplift as the wells on the crest of the structure encounter the Yegua formation at depths that are normal for the area, while the wells on the north flank encounter the Yegua at depths that are several hundred feet below normal. This anomaly appears to be a classical example of a residual high. It is between and downdip from the overlapping rim synclines of the Brookshire and Hockley salt domes (Fig. 1). Closure on the north, east, and west is due to subsidence of these flanks which took place as the peripheral sinks were formed. The salt mass moved from the forming synclines toward the center of the growing salt plugs, leaving a residual high in the interdomal area.

This theory for the origin of the Katy structure, first advanced by C. H. Ritz,¹³ is further supported by the fact that there is an abnormal thickening of the formations on the flanks affected by the peripheral sinks. The interval from the top of the Frio to the base of the Yegua formation increases from 4,787 feet over the crest of the structure to 5,165 feet on the north flank. The total thickening is 378 feet, with 138 feet in the Yegua formation, 107 feet in the Jackson formation, 33 feet in the Vicksburg formation, and 100 feet in the Frio formation. This leads to the assumption that subsidence began prior to the deposition of the Yegua formation and continued throughout that of the Frio.

RESERVOIRS

Production in the Katy field is confined to sands in the Yegua formation between the depths of 6,250 feet and 7,450 feet, a stratigraphic section of approximately 1,200 feet. This interval contains six sand zones, each of which, with the exception of the Cockfield sand, is composed of two or more members. The first and second zones have slightly different water levels in individual sand members, some of which have thin oil intervals.

Figures 4 and 5, geological cross sections, illustrate reservoir conditions and show zonation. These west-east sections are of the north and south parts of the field, respectively.

The Yegua sands are gray, fine- to medium-grained and subangular. Thin partings of lignitic shale probably decrease vertical permeability. These sands

¹³ C. H. Ritz, "Geomorphology of Gulf Coast Salt Structures and Its Economic Application," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20 (1936), p. 1425.

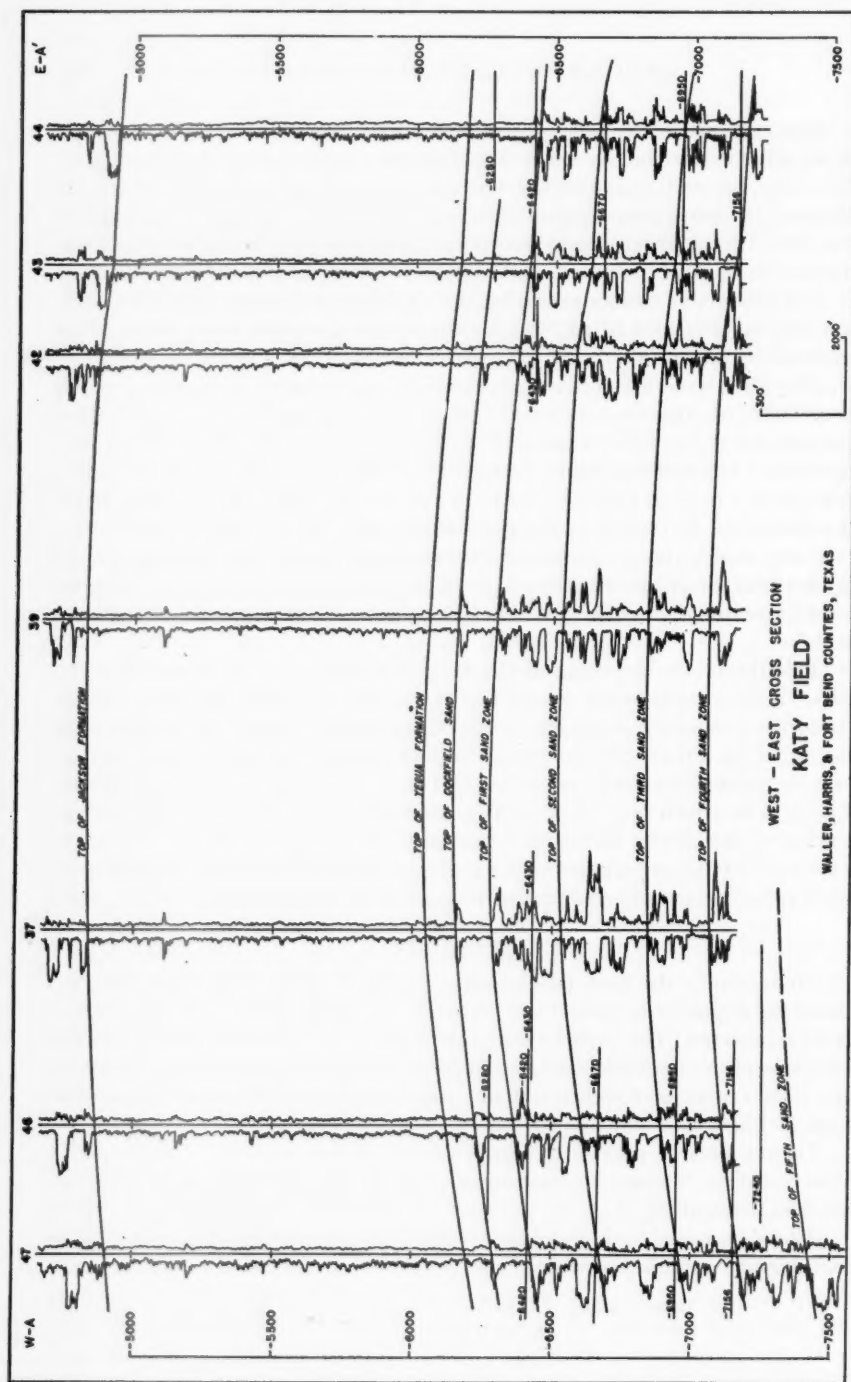


FIG. 4.—Geologic section through Katy field from west to east along line AA' in Figure 2.

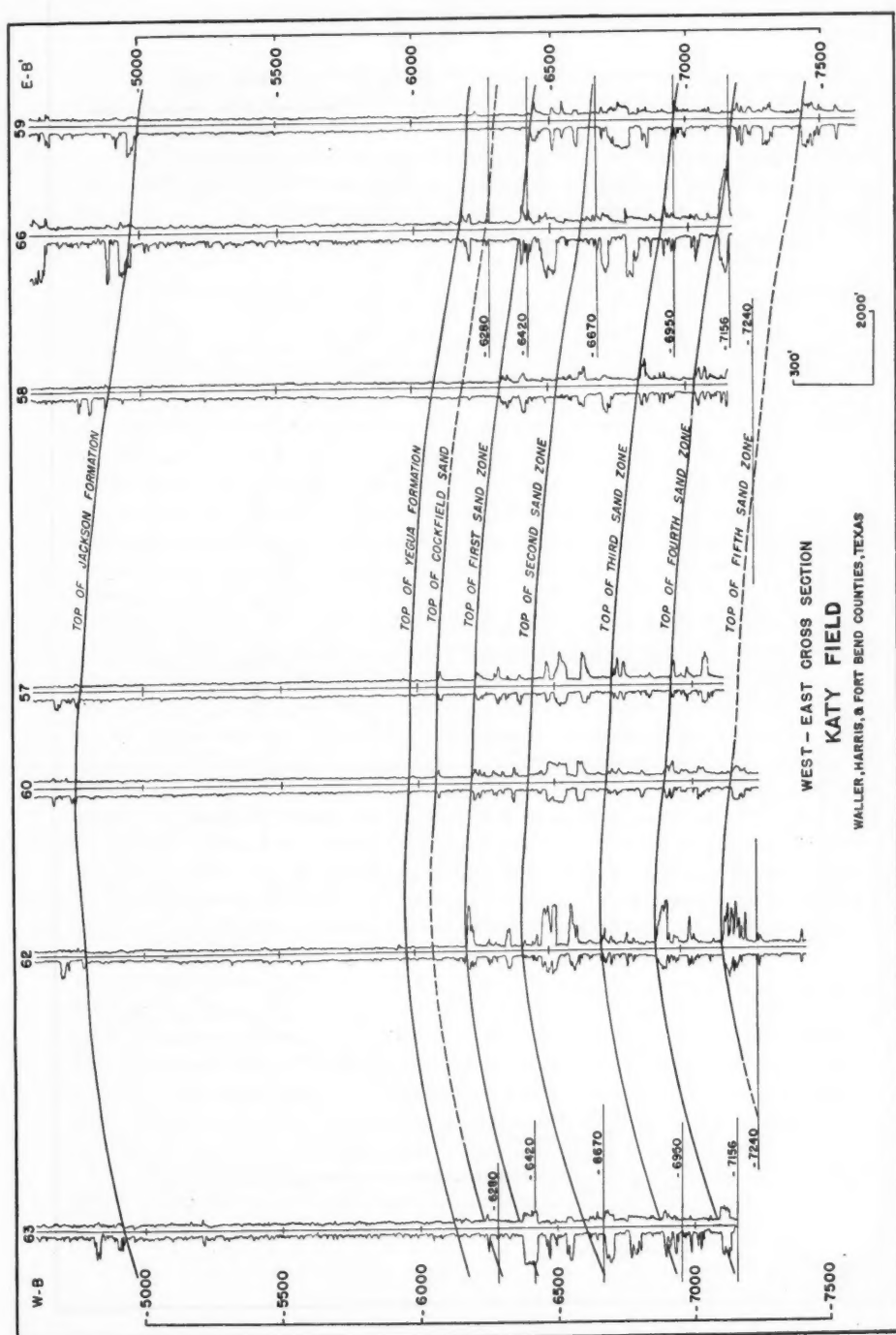


FIG. 5.—Geologic section through Katy field from west to east along line BB' in Figure 2.

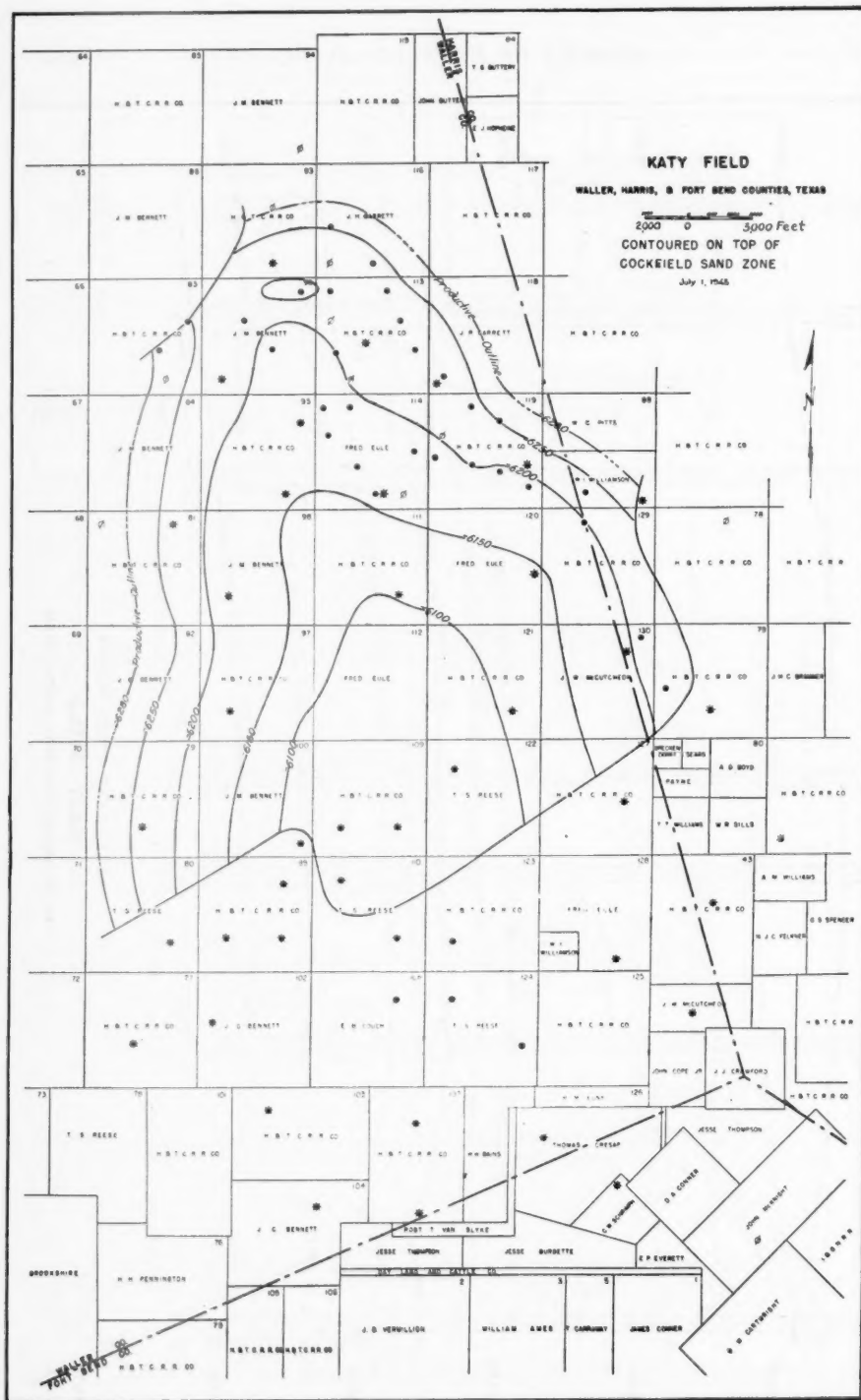


FIG. 6.—Geologic structure map, Katy field. Contours on top of Cockfield sand, subsea depth in feet.

have an average porosity of approximately 27 per cent and an average permeability of 500 millidarcys. Pressure for each of the reservoirs is normal at the depth where it is encountered.

An average fourth zone gas well will produce $7\frac{1}{2}$ to 8 million cubic feet of gas daily through a $\frac{3}{8}$ -inch choke, with a condensate content of 1.125 G.P.M.¹⁴ The fourth zone is the only reservoir being cycled at the present time, with sufficient gas being taken from the fifth zone to replace that used for plant operations and sales.

The individual characteristics of the reservoirs are discussed in the following paragraphs.

Cockfield Sand zone.—There has been no production from the Cockfield sand, but it has been proved capable of producing gas by drill-stem tests of several wells. It has a gas-water contact of 6,280 feet subsea and a maximum effective gas closure of 225 feet. It will be noted by referring to Figures 4 and 5 that this sand occurs as a sand stringer 150 feet above the top of the first zone or the top of the massive Yegua sands. The Cockfield sand is present only in the north two-thirds of the field, having "shaled out" toward the south and in the extreme north-west part of the field. Where present, it has a fairly uniform thickness of approximately 25 feet. Areal distribution of the sand is illustrated by the Cockfield sand structural map (Fig. 6).

First Sand zone.—A structural map on top of the first zone is shown in Figure 7. The top sand member of this zone has a gas-water contact of 6,420 feet subsea. The second member "Pattison sand," has an oil interval developed, at least in the north part of the field, with a gas-oil contact at 6,430 feet subsea and an oil-water contact at 6,442 feet subsea. This zone has a maximum combined gas and oil interval of 255 feet and an average sand thickness of approximately 120 feet.

The top member of this zone is present throughout the field, but is somewhat variable in its development, being more shaly in the southern than in the northern part. The basal member of the zone has a similar development to the first member, neither having an oil interval. The Middle, or Pattison, member exhibits considerable variation, attaining a maximum development of 100 feet in the extreme north end of the field in Section 96, breaking into two shaly members in a southerly direction and is almost completely shaled out in the extreme southwestern part of the field. Due to the lack of sand development and a thin oil interval, oil is present in a narrow belt around the northern flanks of the field, spreading across the north nose of the structure where the sand reaches its maximum development. The comparatively thin oil interval causes considerable difficulty in making successful oil completions. Wells completed initially water-free and with low gas-oil ratios, have invariably made water or produced excessive amounts of gas after a relatively small amount of oil has been recovered.

On July 1, 1945, there were sixteen producing oil wells in the Pattison sand, which is the only production from the first zone.

¹⁴ G.P.M. = gallons per 1,000 cubic feet.

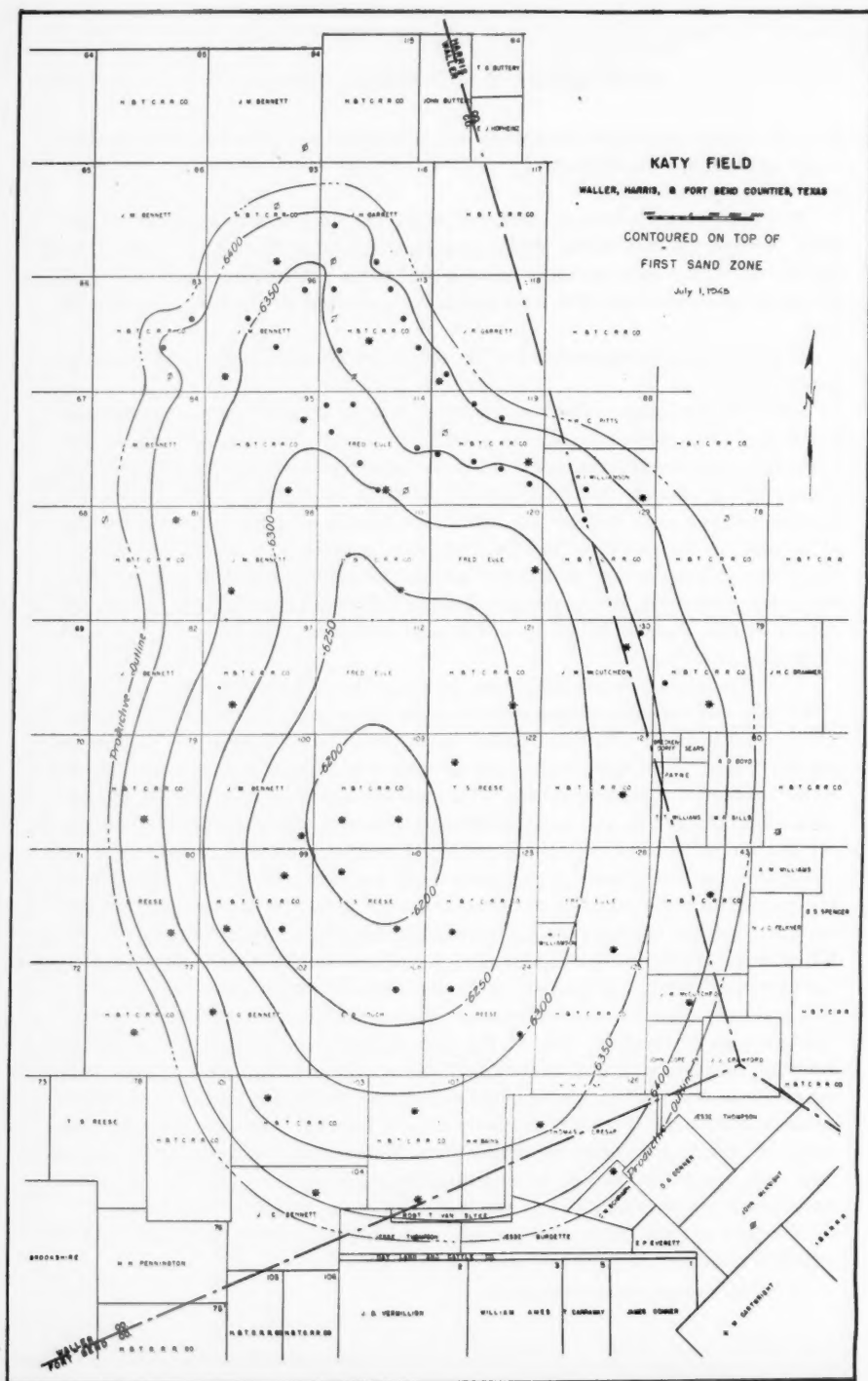


FIG. 7.—Geologic structure map, Katy field. Contours on top of first sand zone, subsea depths in feet.

Second Sand zone.—A structural map with its datum the correlative top of the zone is shown in Figure 8. The upper two members of the zone "shale out" in the central and southern parts of the field. The third and fourth members are continuous over the structure, although the third member varies in its development.

Gas-water contact of the upper member is 6,670 feet subsea. The Hebert and Stockdick oil sands are in the second and third members, respectively. They have thin oil intervals with the gas-oil contact at 6,670 feet subsea and the oil-water contact at 6,680 feet subsea.

Thirteen oil wells have been completed in the second zone, nine of which are in the Hebert sand and four in the Stockdick. More difficulty is experienced in completing oil wells in these sands than in the Pattison of the first zone. Results have been particularly discouraging in the Stockdick sand. Production problems, similar to those encountered in the first zone, prevail in the second zone. As in the first sand zone, oil in the second sand zone is in a narrow belt and is confined to the northern limits of the field. The Ohio's Smock No. 1 (K.G.F.U. II No. 14) is the only gas well completed in this zone.

The zone has a sand thickness of approximately 140 feet, and a maximum combined gas and oil interval of 295 feet, which is the greatest in the field; consequently, the limit of production in this zone constitutes the maximum productive area of the field where the sand is developed to the top of the zone.

Third Sand zone.—Figure 9 is a structural map of the third zone. This datum makes nearly a true structural picture since the upper member of the zone is fairly uniform in its development throughout the field. The lower members, however, are erratic, as illustrated by the geologic cross sections.

A gas-water contact of 6,950 feet subsea prevails for this zone throughout the field. The zone has a maximum gas interval of 270 feet and an average sand thickness of approximately 50 feet. One well, the Humble Oil and Refining Company's Woods No. 1-C (K.G.F.U. II No. 17), has been completed in it.

Fourth Sand zone.—Figure 10 is a structural map with its datum plane on the top of the first sand member or its correlative equivalent. All units of the fourth zone have a common gas-water contact at 7,156 feet subsea, a maximum gas interval of 265 feet, and an average sand thickness of 110 feet. Except that the upper member thins and "shales out" entirely in the northern part of the field, the fourth zone is the most uniformly deposited group of the reservoirs. It constitutes the maximum productive area over the southwest half of the field. Uniformity, together with its large productive area, makes it readily adaptable to cycling.

Presently there are twenty-seven producing gas wells and twelve injection wells completed in Zone IV.

Fifth Sand zone.—A structural map on the first sand of the fifth zone is shown on Figure 11. This zone has a gas-water contact of 7,240 feet subsea, a maximum gas interval of 105 feet and a gross average sand thickness of approxi-

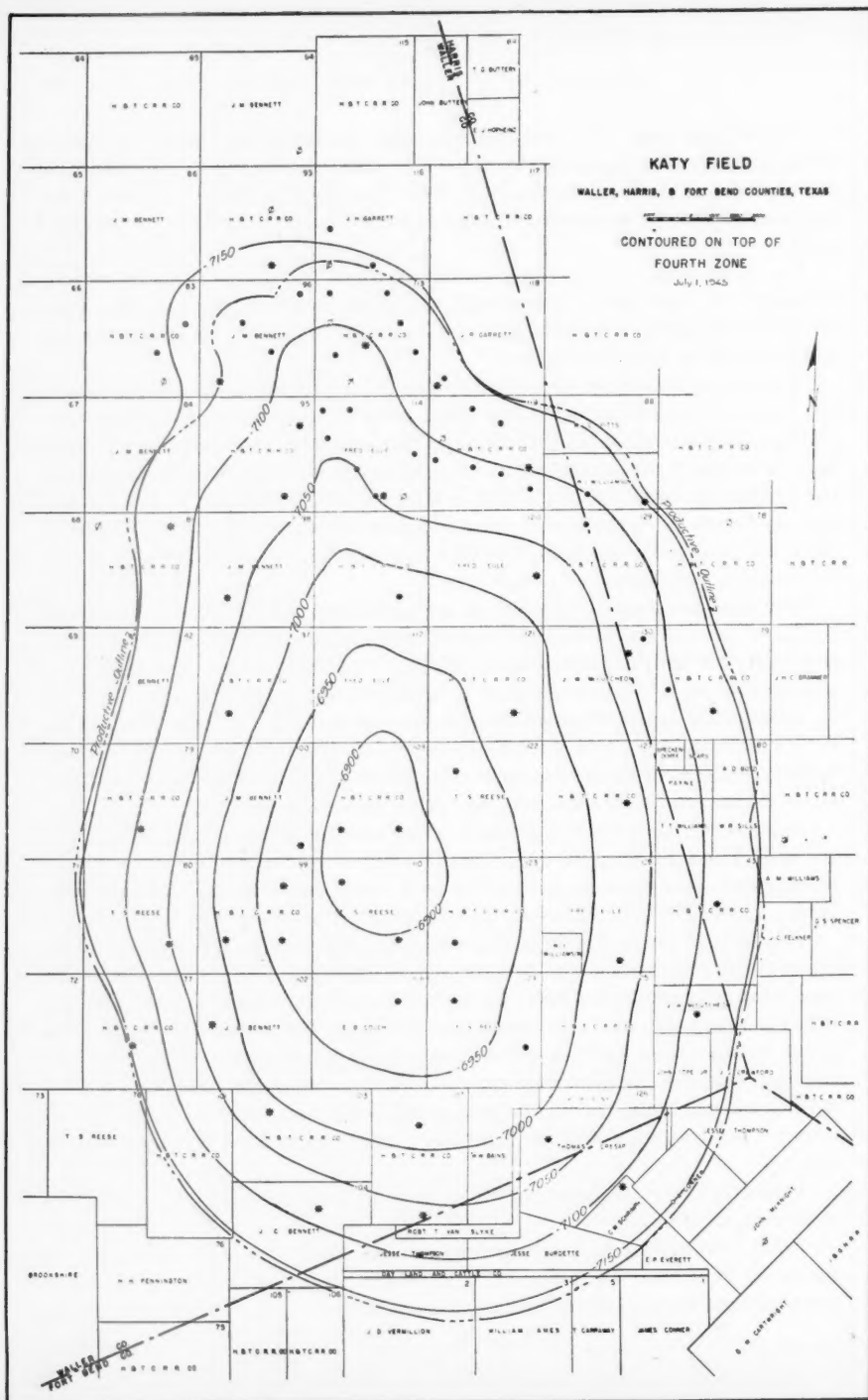


FIG. 10.—Geologic structure map, Katy field. Contours on top of fourth zone, subsea depths in feet.

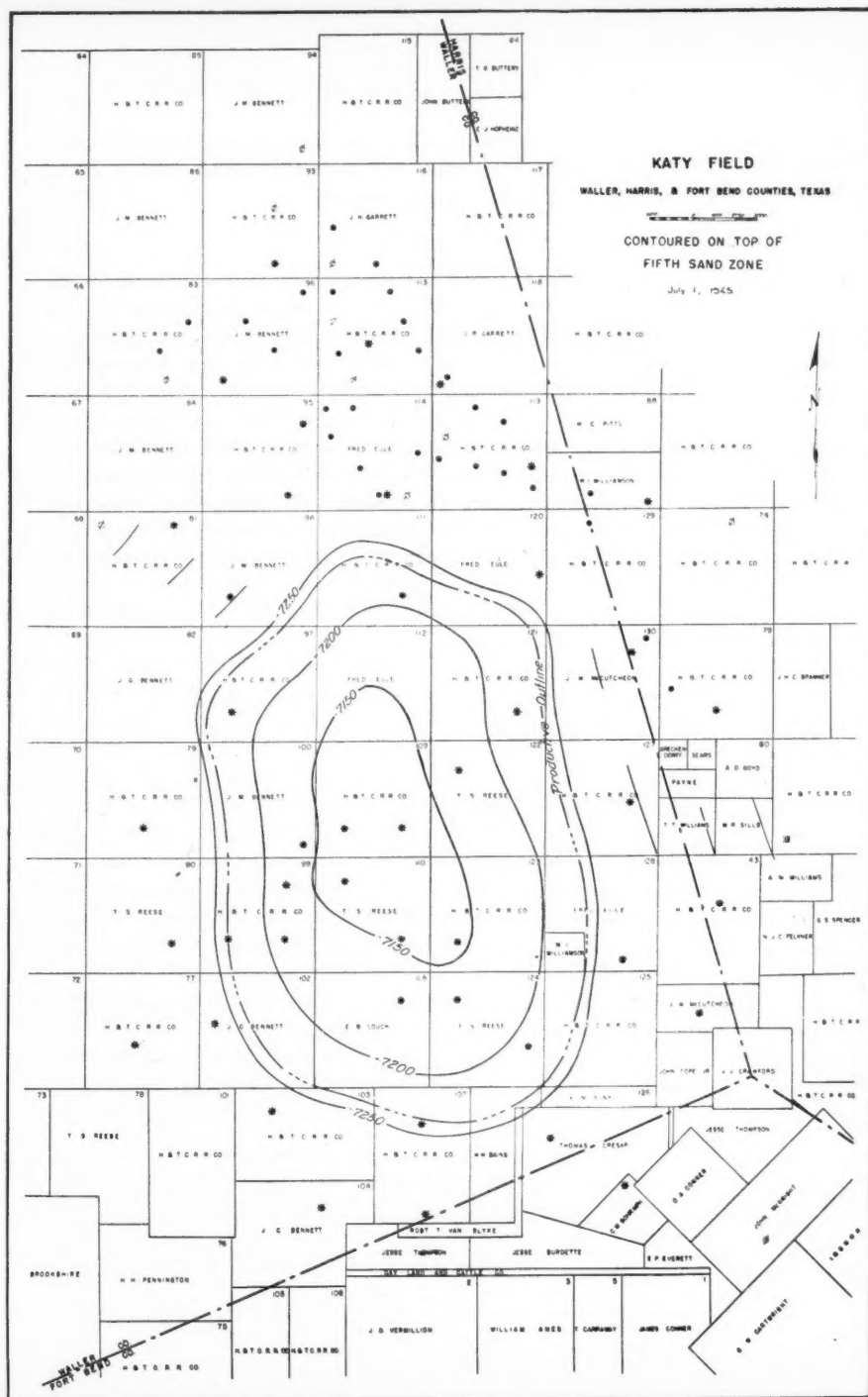


FIG. 11.—Geologic structure map, Katy field. Contours on top of fifth sand zone, subsea depths in feet.

mately 50 feet. The zone consists principally of one massive sand which has uniform development. Its productive area is less than that of any of the other reservoirs and is confined to the crest of the structure.

CONCLUSIONS

The Katy field has a productive area of approximately 30,000 acres and is one of the largest known gas-condensate reserves. It is a simple domal structure, exceptional in the coastal area for its lack of faulting and for its residual origin. Gas-condensate production is proved in six reservoirs of the Yegua formation, and there is minor oil production from parts of two of these reservoirs.

The field is of note as one of the earliest cycling operations and also as one of the first large unitization projections. The true value of the field is realized only by virtue of cycling. On July 1, 1945, there were forty-four gas production or injection wells and twenty-nine oil wells. The average daily production is approximately 15,000 barrels of condensate and oil and 450 million cubic feet of gas. Approximately 375 million cubic feet of gas are being returned to the reservoir.

LOWER PENNSYLVANIAN TERMINOLOGY IN CENTRAL TEXAS¹

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ABSTRACT

Presence of fusiform fusulinids in Marble Falls limestone indicates this formation is post-Morrow in age. Lampasas is not appropriate as a series name, because in its type area it is only partly exposed and because as defined it includes beds of Des Moines age and excludes part of the Marble Falls, which is post-Morrow in age. Elevation of the Atoka formation of Oklahoma to Atoka series and use of this term in Central Texas is proposed.

Study of collections of fusulinid-bearing rocks from the Marble Falls limestone at the type locality, Marble Falls, Texas, and near-by exposures indicates a need for revision of early Pennsylvanian terminology in Central Texas. At Marble Falls, 150 to 200 yards downstream from the Colorado River bridge, the writers recently obtained well preserved specimens of *Pseudostaffella* and a disk-shaped form with short axis of coiling which they are tentatively identifying as *Ozawainella*, associated with numerous specimens of *Millerella*. Distinctly fusiform specimens (positive evidence of post-Morrow age) were obtained from two localities at a similar position in the middle Marble Falls limestone. One of these localities is on a cedar-covered, southwest-facing dip slope, 10 miles airline south-east of Llano, Llano County, and 0.8 mile airline west-northwest of the point where the Llano-Click road crosses Honey Creek. Approximately 250 feet of Marble Falls limestone is exposed overlying Ellenburger limestone. A fusulinid-bearing bed in the middle part of the formation contains a species with a long axis of coiling, probably *Fusiella*. *Pseudostaffella* and *Millerella* are also present. The other locality is on the north bank of Rough Creek, 6.5 miles northwest of Bend on the Bend-San Saba road, where *Pseudostaffella* and *Fusiella* were found. In this same general area and in the areas between Nix (Lampasas County) and Bend, numerous exposures of middle Marble Falls beds have *Pseudostaffella*, *Ozawainella*, and *Millerella* present.

The genus *Millerella* was described by Thompson in 1942³ and was based on specimens collected from the Marble Falls limestone in the bed of the Colorado River at about water level, 150 yards downstream from the bridge at Marble Falls. In the zone from which these *Millerella* specimens came, Thompson did not find other genera except a doubtful *Ozawainella*-like form. In 1944 Thompson⁴

¹ Manuscript received, October 15, 1945.

² Geologists, Shell Oil Company, Incorporated. The writers gratefully acknowledge the assistance of E. Russell Lloyd, R. V. Hollingsworth, Bruce H. Harlton, L. R. Newfarmer, and T. L. Stall, all of whom read the manuscript and offered many valuable suggestions; and they thank the management of the Shell Oil Company, Incorporated, for permission to publish the paper.

³ M. L. Thompson, "New Genera of Pennsylvanian Fusulinids," *Amer. Jour. Sci.*, Vol. 240 (June, 1942), pp. 404-05.

⁴ M. L. Thompson, "Pennsylvanian Morrowan Rocks and Fusulinids of Kansas," *Univ. Kansas Bull.* 52, Pt. 7 (December, 1944), pp. 409-31.

found a fusulinid fauna in the subsurface of Kansas which is composed of abundant representatives of the genus *Millerella*, but from which biologically more highly developed fusulinids are apparently absent. Thompson noted the same occurrence in Morrow rocks at the type locality, Hale Mountain, south of Morrow, Arkansas. This abundance of *Millerella* and the absence of other fusulinid genera led Thompson to designate the Morrowan series as the "zone of *Millerella*."

In the central Texas outcrops of the Marble Falls, the occurrence of *Fusiella*, *Pseudostaffella*, and *Ozawainella*, all of which are more advanced forms than any ever reported from the Morrow, associated with *Millerella*, show that these beds are post-Morrow in age. From other areas where a more complete sequence of rocks is exposed, the range of *Millerella* is known to be from within the Morrow to upper Pennsylvanian. Thompson has reported⁵ a sequence of fusulinids in the lower Pennsylvanian of New Mexico and West Texas in which a zone containing *Millerella* (Morrow in age?) is overlain by a zone in which *Millerella* is associated with *Profusulinella* and *Ozawainella*? (Green Canyon group, Derry series), and this is overlain by a zone in which *Fusulinella*, *Eoschubertella*, *Pseudostaffella*, and *Millerella* occur (Mud Springs group, Derry series). The typical Des Moines genera, *Fusulina* and *Wedekindellina*, appear in overlying beds, and these genera also are associated with *Millerella*. It is evident that fusulinid-bearing beds of the Marble Falls limestone are correlatives of part of the Derry series of New Mexico. For reasons discussed in the following paragraphs, the writers prefer not to use Derry as a series term in Central Texas.

Overlying Marble Falls beds in the vicinity of Bend, eastern San Saba and western Lampasas counties, is the Smithwick shale, composed of limestone beds at the base, overlain by dark gray shale. So far as the writers know, fusulinids have not been found in the Smithwick shale on the east side of the Llano uplift. Harlton⁶ has found a zone containing *Eusulinella*, 0.75 mile south of the village of Bend on a tributary of Cherokee Creek. The Marble Falls-Smithwick boundary is gradational and the contact is obscure but Harlton believes this zone is properly assigned to the Marble Falls. Correlatives of the upper Marble Falls and Smithwick on the west side of the Llano uplift are known to contain abundant representatives of *Fusulinella*. The fusulinids from these strata are similar to forms collected by the writers from the upper part of Thompson's Derry series of New Mexico and from Atoka beds (Barnett Hill, Bostwick, and Lester formations) of Oklahoma. Thompson⁷ has discussed the occurrence of a group of closely related species of *Fusulinella*, perhaps a sub-genus, which characterizes the "zone of *Fusulinella*" and which occurs in rocks of pre-Des Moines age. The writers have observed this group of *Fusulinella* species in numerous outcrops of early

⁵ M. L. Thompson, "Pennsylvanian System in New Mexico," *New Mexico School Mines Bull.* 17 (1942), p. 29.

⁶ B. H. Harlton, personal communication, August 21, 1945.

⁷ M. L. Thompson, *op. cit.*, p. 29.

Pennsylvanian rocks and in cuttings from several hundred wells in Texas and Oklahoma. The "zone of *Fusulinella*" has been found to underlie beds containing *Fusulina* and *Wedekindellina* wherever a sequence of fusulinids has been obtained throughout lower Pennsylvanian strata. The zones apparently do not overlap.

Based on the occurrence of this group of *Fusulinella* (restricted) species, the Smithwick shale is to be correlated with the Eastland Lake group of the subsurface.⁸ Cheney's overlying Caddo Pool and Parks groups⁹ contain abundant representatives of the genera *Wedekindellina* and *Fusulina* and a few *Fusulinella* species which are more advanced than those in Marble Falls or Smithwick beds.

In 1940 Cheney¹⁰ restricted the term Marble Falls to include only beds of Morrow age occurring in the vicinity of Marble Falls. The discovery of post-Morrow fusulinids in the middle part of the Marble Falls and the absence of any apparent physical break in the limestone below the fusulinid-bearing zone makes the presence of Morrow doubtful in this area. If Morrow beds are present at all in the type Marble Falls, only a small part of the lower part could be so classified, and until some evidence of its Morrow equivalence is found the writers believe the beds at Marble Falls should be regarded as post-Morrow in age. Also, they believe the term "Marble Falls" should be restored to its former meaning, that is, to include all the beds at Marble Falls and equivalent beds in other parts of central Texas.

Near Bend the lower part of the Smithwick contains a considerable amount of limestone. The proportion of limestone and shale in both the Marble Falls and the Smithwick is variable, and the usual practice in mapping is to regard the limestone as Marble Falls and the shaly part as Smithwick.

Cheney¹¹ proposed the Lampasas in 1940 as a series to include post-Morrow, pre-Strawn (Des Moines) beds of Central and North Texas. The type locality was given as Lampasas County where Big Saline (upper Marble Falls) and Smithwick were included in the series, but in cross sections the series was shown as including the subsurface Caddo Pool-Parks beds which contain the typical Des Moines genera *Fusulina* and *Wedekindellina*. Thus, as then defined, the Lampasas was equivalent to the Bend group minus the so-called Morrow beds of the Marble Falls. In the 1944 classification chart of the Pennsylvanian subcommittee of the National Research Council, the same usage of the Lampasas series was followed.¹² In the 1945 Pennsylvanian classification of Cheney and others, the

⁸ M. G. Cheney *et al.*, "Classification of Mississippian and Pennsylvanian Rocks of North America," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 2 (February, 1945), p. 162.

⁹ M. G. Cheney, "Geology of North-Central Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 1 (January, 1940), p. 86.

M. G. Cheney *et al.*, *op. cit.*, pp. 162-63.

¹⁰ M. G. Cheney, *op. cit.*, p. 83.

¹¹ M. G. Cheney, "Geology of North-Central Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 1 (January, 1940), p. 81.

¹² R. C. Moore *et al.*, "Correlation of Pennsylvanian Formations of North America," *Bull. Geol. Soc. America*, Vol. 55 (June 1944), Pl. 1 (facing p. 706).

Lampasas series was expanded¹³ to include all the beds up to the top of the Dennis Bridge limestone, which is approximately equivalent to the Inola limestone of Oklahoma. By this definition it includes equivalents of the Atoka formation of Oklahoma and the Derry series of New Mexico, plus approximately half of the Cherokee group of Oklahoma, Kansas, and Iowa. In the upper part of the Lampasas series (Caddo Pool and Parks groups), the writers have found most of the species of *Wedekindellina* so far described from North America and a considerable number of species of *Fusulina* and a few of advanced-type *Fusulinella*.

The Des Moines series of the Mid-Continent area has been recognized as the "zone of *Fusulina*" by so many writers it does not require further discussion. The "zone of *Wedekindellina*" is just as valuable, stratigraphically, because this genus ranges from near the base to near the top of the Cherokee group, which is lower Des Moines. *Wedekindellina ultimata* Newell and Keroher, in the lower Missouri series of Kansas and Missouri, is sufficiently different from *Wedekindellina* of the Cherokee group that the writers prefer to assign it to another genus, possibly Thompson's *Waeringella*.¹⁴

In the opinion of the writers the occurrence of *Wedekindellina* and *Fusulina* in the Caddo Pool and Parks beds makes it desirable to exclude these beds from the same series that includes the "zone of *Fusulinella*" (restricted) and to include them with other *Fusulina*- and *Wedekindellina*-bearing beds in the Des Moines (or Strawn) series. The Lampasas series would thereby be restricted to include the zone containing *Fusulinella* (restricted), *Fusiella* (and/or *Profusulinella* if it is a valid genus), *Pseudostaffella*, and *Ozawainella*.

In Cheney's¹⁵ discussion of the Pottsville-Allegheny boundary problem in the report of the Association subcommittee on Carboniferous, he cites several possible choices for selecting the boundary in the Oklahoma section. One of these possible boundaries is between Atoka and Hartshorne beds. This seems to correspond with the faunal break between the zone of *Fusulinella* (restricted) and the zone of *Wedekindellina* and *Fusulina*. Higher boundaries listed are within the latter zone. The post-Atoka unconformity seems to have more regional significance than the several small unconformities or disconformities within the *Wedekindellina*-*Fusulina* zone. In the Ouachita outcrops of southeastern Oklahoma, Atoka beds are involved in the thrusting while Des Moines beds are not included. Beds equivalent to the Atoka thin over the Concho arch northwest of the Llano uplift, apparently by truncation. In the southern Midland basin, Atoka equivalents occur in small areas without apparent relationship to folds involving Des Moines beds. In the Strawn basin, to the northeast of the Llano uplift, and

¹³ M. G. Cheney *et al.*, "Classification of Mississippian and Pennsylvanian Rocks of North America," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 2 (February, 1945), p. 163.

¹⁴ M. L. Thompson, "New Genera of Pennsylvanian Fusulinids," *Amer. Jour. Sci.*, Vol. 240 (June, 1942), pp. 413-14.

¹⁵ M. G. Cheney *et al.*, "Classification of Mississippian and Pennsylvanian Rocks of North America," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 2 (February, 1945), pp. 147-56.

in the Kerr basin, on the south, several hundred feet of *Fusulinella* (restricted)-bearing beds formerly regarded as Strawn in age occur above Marble Falls-Smithwick and below Des Moines (Strawn). These beds are not present in the Bend Arch area. Possibly they were deposited and later removed by erosion, but, more likely, they were never deposited over the Bend arch. At any rate, a time break is indicated in this area even though the physical break in the sediments is not obvious. Throughout most of North-Central and West Texas, lower Des

TABLE I
OUTLINE OF PROPOSED PENNSYLVANIAN SERIES IN CENTRAL TEXAS

Virgil and Missouri series shown essentially as in current use. Boundaries of Des Moines series adjusted so as to include all *Fusulina*- and *Wedekindellina*-bearing beds in area. Atoka series is new.

Proposed Pennsylvanian Series	Beds Included in Series	Fusulinid Zones
Virgil (Cisco)	Top of upper Crystal Falls limestone to base of Kisinger Channel sandstone	<i>Triticites</i> , various species <i>Dunbarinella</i> <i>Waeringella spiveyi</i>
Missouri (Canyon)	Top of Home Creek limestone to base of Lake Pinto sandstone	<i>Triticites</i> , various related species <i>Triticites ohioensis</i> <i>Triticites irregularis</i> "Wedekindellina" <i>ultima</i>
Des Moines (Strawn)	Top of Capps limestone to base of Caddo Pool limestone	<i>Fusulinella</i> (advanced type) <i>Fusulina</i> <i>Wedekindellina</i>
Atoka	Unnamed subsurface beds Smithwick Marble Falls	<i>Fusulinella</i> (restricted) <i>Fustiella</i> <i>Profusulinella?</i> <i>Ozawainella</i> <i>Pseudostaffella</i>
Morrow	Possibly not represented, unnamed if present	<i>Millerella</i> ; with absence of all the more advanced forms previously listed

Moines (Caddo Pool-Parks) beds are present, and they rest on beds of all ages from pre-Cambrian to Atoka. This seems to the writers to be very good evidence that the more important regional unconformity is post-Atoka, pre-Des Moines rather than within the lower Des Moines

Because of important faunal (fusulinid) breaks from Morrow to Atoka and from Atoka to overlying beds, and because of important unconformities which correspond with these faunal breaks, and because these sediments comprise a thick complex sequence of beds, the writers propose that the Atoka formation be elevated to Atoka series and defined to include all the beds from the top of the Wapanucka limestone, Morrow series, to the base of the Hartshorne sandstone, Des Moines series. In this series the writers would place the Marble Falls,

Smithwick, and overlying *Fusulinella* (restricted)-bearing beds of Central and North Texas, the Derry series of New Mexico and West Texas, and equivalent beds in other areas as equivalence is established. The Atoka series seems to be a better name and type locality for these beds than the term "Derry," because the Derry at its type locality is only about 130 feet thick, whereas the Atoka beds reach 7000 feet in thickness. The term "Atoka" is preferred, rather than a redefined Lampasas series, because a considerable amount of the upper part of these "zone-of-*Fusulinella* (restricted)" beds is not exposed and is not readily available to workers outside the oil companies for study. The older term, "Bend" group or series, is not applicable for the same reason and also because its use incorrectly implies correlation of the Smithwick with Caddo Pool and part of the Parks groups of the subsurface. Table 1 summarizes the series subdivisions of the Pennsylvanian of Texas as the writers propose to use them.

So far as the writers know, the name Atoka as a series has not previously been suggested in print except that Cheney stated¹⁶ it had been proposed in an unpublished manuscript by Lowman and Ware. It also appeared on a table prepared by the Tulsa Stratigraphic Society¹⁷ in 1938; and Hollingsworth,¹⁸ in his discussion of the Derry series in a review of Thompson's "Pennsylvanian System in New Mexico," stated:

Had the designation "Atoka" been applied to this incomplete sequence the continuity of Mid-Continent series terminology would have been preserved. This would serve to clarify, rather than confuse, the already cumbersome Pennsylvanian terminology.

Many geologists in Oklahoma and Texas have made informal use of the Atoka as a series for several years.

¹⁶ M. G. Cheney *et al.*, "Classification of Mississippian and Pennsylvanian Rocks of North America," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 2 (February, 1945), p. 148.

¹⁷ Tulsa Stratigraphic Society, "Composite Surface Section in the Vicinity of Tulsa" (1938).

¹⁸ R. V. Hollingsworth, Review of Thompson's, "Pennsylvanian System in New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, No. 8 (August, 1943), p. 1159.

PRE-SELMA UPPER CRETACEOUS STRATIGRAPHY OF WESTERN ALABAMA¹

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ABSTRACT

The pre-Selma Upper Cretaceous deposits of western Alabama have long been divided into the Tuscaloosa and Eutaw formations but recent field work shows that six stratigraphic units of formational rank can be mapped:

	Eutaw formation
	McShan formation
Tuscaloosa group	{ Gordo formation
	{ Coker formation
	{ Eoline formation
	{ Cottondale formation

The contacts separating these units are unconformable with the possible exception of that between the Cottondale and the Eoline formations.

The Cottondale formation consists of cross-bedded fine to coarse, somewhat gravelly sand and carbonaceous clay that locally contains a rich flora. In origin it may be entirely continental or in part marine.

The Eoline formation is a marine formation which commonly consists of cross-bedded glauconitic sand overlain by laminated somewhat carbonaceous clay.

The Coker formation consists of highly cross-bedded and lenticular beds of sand and ferruginous clay, and is probably non-marine.

The Gordo formation also consists of cross-bedded sand and mottled ferruginous and carbonaceous clay, but is the only formation of the Tuscaloosa group that contains large amounts of gravel. Throughout the area thus far studied in detail most of the gravel is chert. The formation is probably non-marine.

The McShan formation is marine and has generally been included with the Eutaw formation, but an important and widespread unconformity separates it from the restricted Eutaw. It consists of finely glauconitic very fine sand and laminated sandy clay.

The Eutaw formation, in contrast to the McShan, contains much coarser glauconite and much more compact gray shale. The top member of the Eutaw is the oldest Cretaceous bed that contains abundant fossilshells on the outcrop.

All six formations have been recognized in wells as far down dip as Lauderdale and Neshoba counties, Mississippi.

INTRODUCTION

A study of the stratigraphy of the pre-Selma Upper Cretaceous rocks cropping out in Alabama and Mississippi was begun in May, 1944, by the United States Geological Survey as a part of its war-time program of oil and gas investigations. Numerous petroleum geologists interested in the producing oil sands in Mississippi suggested the project in the hope that study of the stratigraphic relations of the outcropping beds would solve problems of subsurface correlation. W. H. Monroe, L. C. Conant, D. H. Eargle, and J. H. Morris were assigned to the project and were assisted part time by Mrs. Margaret Ann Morris as field assistant. The Geological Survey of Alabama and the Department of Geology of the University of Alabama are cooperating in the project. H. D. Miser, L. W.

¹ Manuscript received, November 16, 1945. Published by permission of the director of the Geological Survey, United States Department of the Interior.

² Geologists, Geological Survey, United States Department of the Interior.

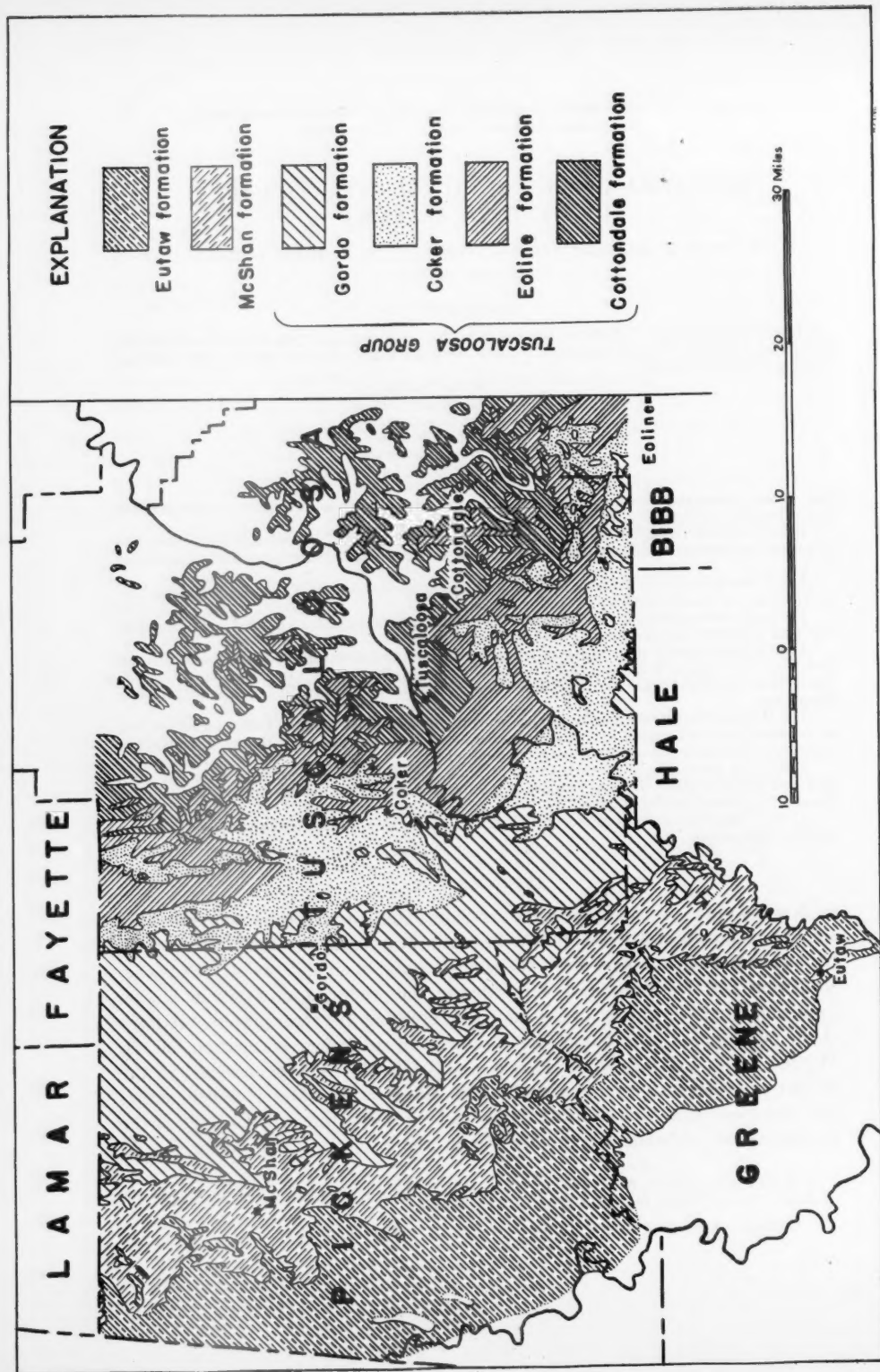


FIG. 1.—Generalized map of pre-Selma Upper Cretaceous formations in western Alabama.

Stephenson, C. S. Ross, and R. W. Brown, all of the Geological Survey, have given valuable field and laboratory advice, as have many visiting petroleum geologists.

Publication of the results of the field work is being expedited by use of the Geological Survey's series of Preliminary Oil and Gas maps and charts. The first unit, consisting of the Upper Cretaceous geology of the Tuscaloosa and Cottondale quadrangles, has been published as *Preliminary Oil and Gas Map 37*. The next two units, now in process of publication, include *Preliminary Chart 20*, well sections from Tuscaloosa down dip to Neshoba County, Mississippi, showing detailed lithologic descriptions and suggested correlations; and *Preliminary Map 50*, which shows the geology of the Eutaw Quadrangle and the pre-Selma portions of the unpublished Aubrey, Aliceville, Mantua, and Mt. Hebron quadrangles. In preparation are a third map unit covering a strip of five quadrangles from the Searles Quadrangle on the east to the Tombigbee River in Mississippi on the west, and a reconnaissance map of the pre-Selma Cretaceous rocks of Mississippi and Alabama. It is anticipated that field work on the project will be completed in 1946.

Up to the time of writing this report (October, 1945) detailed stratigraphy of the pre-Selma beds has been investigated in the region between the northern edge of Pickens and Tuscaloosa counties on the north and the Cahaba River on the east (Fig. 1). Reconnaissance investigations northward as far as Marion County, Alabama, and Tishomingo County, Mississippi, indicate progressive overlap in that direction, whereas similar investigations as far eastward as Chilton County indicate that most, perhaps all, of the Tuscaloosa section is present that far east.

PREVIOUS INVESTIGATIONS

The pre-Selma Upper Cretaceous rocks of Alabama and Mississippi have long been divided into two formations—the Tuscaloosa and the Eutaw.

The Tuscaloosa formation was first formally described and named by Smith and Johnson³ in 1887 to include the variegated clay, sand, and gravel between the Paleozoic rocks and the Eutaw formation. The beds to which they applied Tuscaloosa had been formerly included in the Eutaw by Hilgard. Tuscaloosa sections described as typical were those on the Tuscaloosa (Warrior) River at Steeles Bluff and Whites Bluff (both included below in the proposed Gordo formation) and those in the large gullies near Havana in Hale County (included in the proposed McShan formation). Although Smith and Johnson summarized observations on these beds which earlier writers had assigned to various ages from Triassic to Tertiary, they had insufficient evidence to date the beds more closely than older than Eutaw and younger than Carboniferous.

By 1894 plants had been collected from various parts of the formation and Smith was able to show the entire formation to be Cretaceous in age.⁴

³ E. A. Smith and L. C. Johnson, "Tertiary and Cretaceous Strata of the Tuscaloosa, Tombigbee and Alabama Rivers," *U. S. Geol. Survey Bull.* 43 (1887), pp. 95-116.

⁴ E. A. Smith, L. C. Johnson, and D. W. Langdon, Jr., "Report on the Geology of the Coastal Plain of Alabama," *Geol. Survey of Alabama*, Montgomery (1894), pp. 312-14.

Stephenson⁵ in 1914 called attention to glauconite in the lower part of the Tuscaloosa deposits—the first hint that a part of the Tuscaloosa might be marine.

Berry⁶ in 1919 published numerous detailed descriptions of typical sections of the Tuscaloosa and Eutaw formations and from his studies of the floras made several surmises confirmed in recent work. He pointed out that the beds assigned to the Tuscaloosa formation in northern Alabama and Mississippi are younger than the plant-bearing beds at the south near the city of Tuscaloosa; the present investigation has shown that the Tuscaloosa formation of northern Alabama is a part of the youngest of four proposed formations, whereas the plant-bearing beds near the city of Tuscaloosa belong to the two oldest formations. He called attention to the glauconite in the Tuscaloosa deposits near Tuscaloosa city; the glauconite is found to be in the proposed Eoline formation. He pointed out that the basal Tuscaloosa in northern Alabama is principally gravelly sand, whereas the basal Tuscaloosa near Tuscaloosa city contains much clay; recent work shows that the formations near Tuscaloosa are overlapped toward the north by the much more gravelly Gordo formation. Recent work, however, does not confirm his view that the Tuscaloosa grades down-dip into the Eutaw and the Eutaw into the Selma—rather the surface units appear to continue far down the dip and to be separated by widespread unconformities.

The Mississippi Geological Society⁷ in 1941 pointed out that in central Mississippi and western Alabama three lithologic zones, including a middle marine zone, could be recognized in subsurface beds of Tuscaloosa age.

Munyan⁸ in 1943 called attention to a middle marine zone in beds of Tuscaloosa age in wells in southeast Alabama, and in Georgia and South Carolina.

McGlothlin⁹ in 1944 made a major contribution to the understanding of the stratigraphy of the Tuscaloosa when he pointed out that in wells the Tuscaloosa consists of four distinct units with a major unconformity between the upper two. This has been confirmed by the present surface work.

The Eutaw formation, as first named by Hilgard¹⁰ in 1860, included all the Cretaceous strata between the Carboniferous and his Tombigbee group but Smith and Johnson, as previously mentioned, separated the Tuscaloosa from the Eutaw

⁵ L. W. Stephenson, "Cretaceous Deposits of the Eastern Gulf Region," *U. S. Geol. Survey Prof. Paper 81* (1914), p. 20.

⁶ E. W. Berry, "Upper Cretaceous Floras of the Eastern Gulf Region in Tennessee, Mississippi, Alabama, and Georgia," *U. S. Geol. Survey Prof. Paper 112* (1919), pp. 7-36.

⁷ Mississippi Geological Society Study Group Project, "Subsurface Sections of Central Mississippi, chiefly Cretaceous," Jackson, Mississippi (March, 1941), pp. 4-5, cross sections 9 and 10.

⁸ A. C. Munyan, "Subsurface Stratigraphy and Lithology of Tuscaloosa Formation in South-eastern Gulf Coastal Plain," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, No. 5 (May, 1943), pp. 596-607.

⁹ Tom McGlothlin, "General Geology of Mississippi," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28, No. 1 (January, 1944), pp. 40-43.

¹⁰ E. W. Hilgard, "Report on the Geology and Agriculture of Mississippi," Jackson (1860), pp. 62-75.

and they added Hilgard's Tombigbee group to their restricted Eutaw. Stephenson¹¹ in 1914 proposed that Hilgard's Tombigbee group be considered an upper member of the Eutaw formation, the Tombigbee sand member.

PROPOSED STRATIGRAPHIC CLASSIFICATION

Early in the present investigation it was found that the Tuscaloosa formation in the type area is made up of four distinct lithologic and stratigraphic units and that the Eutaw formation apparently is made up of two units. Because of the widespread use of the name Tuscaloosa it seemed best to raise the Tuscaloosa to the rank of group rather than to restrict it to any one of the four constituent units. In ascending order the proposed formations of the Tuscaloosa group are the Cottondale formation consisting of somewhat gravelly sand and carbonaceous clay, the Eoline formation consisting of marine glauconitic sand and laminated clay, the Coker formation consisting of light-colored highly cross-bedded probably nonmarine sand and mottled more or less sideritic clay, and the Gordo formation consisting of a thick gravelly sand overlain by interbedded purple-mottled clay and cross-bedded sand locally containing a little gravel. Unconformities are present at the base of the Cottondale, Coker, and Gordo formations, and locally the Eoline seems to rest unconformably on the Cottondale. Preliminary investigations indicate that the Cottondale and Eoline formations are overlapped by the Coker between Winfield and Hamilton in northwestern Alabama, and a thin section of Coker still farther north indicates that it is overlapped in turn by the Gordo. It is probable that the only formation of the Tuscaloosa group cropping out in Mississippi is the Gordo.

The Gordo formation is overlain unconformably by beds of finely glauconitic sand and laminated clay that have generally been considered the Eutaw in Alabama though in Mississippi the presence of a marked unconformity at the top of this unit caused Stephenson and Monroe¹² to assign the unit to the Tuscaloosa. The present investigation has shown that the unit is separated from both the Gordo and the Eutaw formations by unconformities of regional extent and the name McShan is here proposed for the formation.

The McShan formation is overlain unconformably by the restricted Eutaw formation which consists principally of cross-bedded to massive coarsely glauconitic sand containing subordinate amounts of compact dark gray shale and softer light gray clay. The upper 100 feet or less of the Eutaw formation consists of massive glauconitic sand whose upper part is more or less calcareous and fossiliferous—the Tombigbee sand member.

The Tombigbee sand member of the Eutaw formation is overlain sharply by the basal sandy bed of Mooreville chalk of the Selma group.

¹¹ L. W. Stephenson, "Cretaceous Deposits of the Eastern Gulf region," *U. S. Geol. Survey Prof. Paper* 81 (1914), pp. 12-14.

¹² L. W. Stephenson and W. H. Monroe, "The Upper Cretaceous Deposits (of Mississippi)," *Mississippi Geol. Survey Bull.* 40 (1940), pp. 38-40.

COTTONDALE FORMATION

The Cottondale formation is typically exposed in cuts of the Southern Railway $\frac{1}{2}$ to $1\frac{1}{2}$ miles east of the village of Cottondale, Tuscaloosa County. The formation is defined as the more or less gravelly sand and associated clay between the base of the Tuscaloosa group and the overlying marine beds of the Eoline formation. Commonly 25 to 75 feet of cross-bedded slightly micaceous sand, which is coarser or even gravelly at the base, is overlain by 2 to 8 feet of carbonaceous or lignitic clay, but at many places dark gray and purple clay are interbedded with the sand, and at a few places nearly the entire interval is represented by dark gray to purple clay as much as 50 to 60 feet thick. A striking characteristic of the gravel, nearly everywhere confined to the basal part, is the presence of abundant polished disc-shaped quartz pebbles of several colors. The abundance of such discs is suggestive of wave and tidal action on a seashore, though no other evidences of marine environment have been recognized in the Cottondale deposits.

In the railway cuts at the type locality east of Cottondale (Sec. 25, T. 21 S., R. 9 W.) about 40 feet of sand and gravel can be seen resting on weathered sandstone of Pottsville (Pennsylvanian) age. In the first cut east of Cottondale 6 feet of gravel near the base is overlain by 40 feet of cross-bedded sand and carbonaceous clay; in the next big cut $\frac{1}{2}$ mile farther east, gravel and clay are almost entirely absent, and in the next two cuts (both sides of block signals) 12 to 15 feet of gravelly sand is overlain by 15 feet of sand. Quartz pebbles predominate in the gravel, with discs abundant, though some chert and a few pebbles from the Pottsville formation are present. The average length of the pebbles is about 1 inch, but some are as long as 3 inches. In the cuts near the block signals some of the gravel has been indurated and rests on conglomerate of the Pottsville formation. A total thickness here of about 75 feet of Cottondale deposits is suggested by light-colored sandy soil and scattered poor exposures on the adjacent wooded hills and cultivated fields.

The differences which occur in short distances are strikingly illustrated by the presence 1 mile south of the railway cuts of a thick section of massive and jointed clay exposed in a badly gullied area (near center of Sec. 36, T. 21 S., R. 9 W.) $1\frac{1}{2}$ miles southeast of Cottondale just north of the Cottondale-Coaling road. Here about 12 feet of silt and silty clay and thin sand beds just above the Paleozoic rocks are overlain by 50 feet of dark gray and purple clay, the top of which is not exposed. The lower half of the clay interval consists chiefly of slightly bedded silty and micaceous clay which contains leaf fragments, and the upper half is chiefly clay which weathers to purple, red, and green hues. Near the base of the upper half, just below a carbonaceous zone, two or three nodules have been found which resemble those of the granular siderite found more abundantly in clay of the Coker formation. This is almost certainly the locality from which Berry¹³ collected his Cottondale fossils, though it should be pointed out that the

¹³ E. W. Berry, *op. cit.*, pp. 18-19.

graphic section published by Berry is clearly of a locality $\frac{1}{2}$ mile farther east where L. W. Stephenson, his companion on a 1909 collecting trip, measured a section, the upper 41 feet of which is Eoline (Berry's beds 1-6). The base of the Eoline formation is here taken to be a distinctly glauconitic sand about a foot thick which rests abruptly and irregularly on the underlying clay (Berry's beds 7-8). This appears to mark a minor unconformity, though the presence of doubtful glauconite as much as 6 feet lower in sand stringers suggests that there is

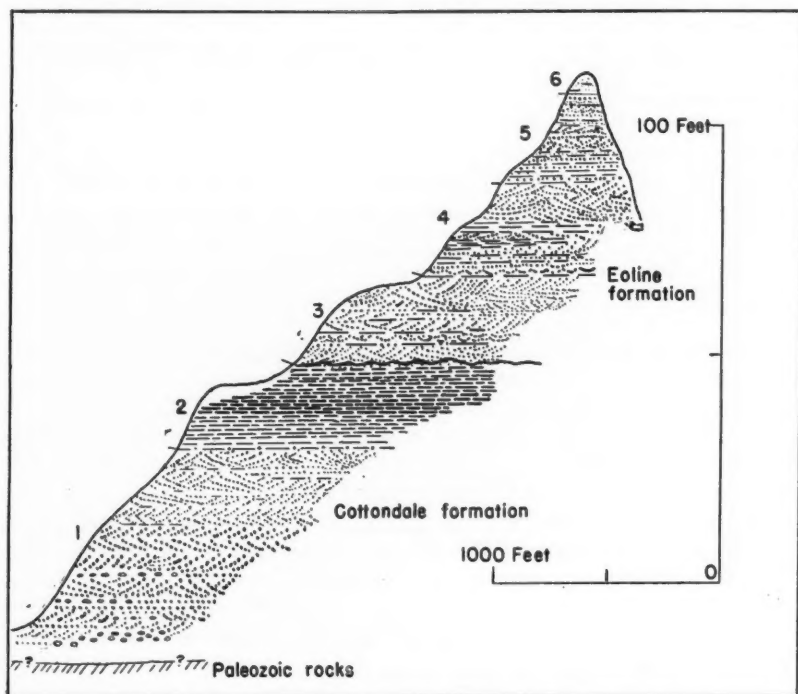


FIG. 2.—Profile section of Cottdale and Eoline formations, 2 miles east of Coaling, Alabama.

here no significant break between the two formations and that locally the uppermost Cottdale beds foreshadow the encroachment of the sea. No rich flora is known at this locality, but Stephenson's notes indicate clearly that a collection was made at the thick clay outcrop $1\frac{1}{2}$ miles southeast of Cottdale.

The characteristic upward succession from gravelly sand to carbonaceous clay of the Cottdale formation, and to glauconitic sand of the Eoline formation is shown by the following section 7 miles farther east, about 2 miles east of Coaling

along a local road (S. $\frac{1}{2}$ Sec. 6, T. 22 S., R. 7 W.), and graphically shown in Figure 2.

SECTION 2 MILES EAST OF COALING, WEST SLOPE OF HILL ON COUNTY
ROAD SOUTH OF SOUTHERN RAILWAY

(Numbers refer to beds in graphic section, Fig. 2).

	<i>Feet</i>
Eoline formation	
6. Light red, yellow, and gray, mottled, weathered massive clayey sand; 1- to 4-inch ferruginous sandstone layer at base. To top of cut.....	6
5. Light red finely cross-bedded micaceous and glauconitic fine to medium sand, grading downward into thin-bedded sand and clay.....	20
4. Red finely cross-bedded micaceous fine to medium sand containing pale glauconite and a few clay flakes; lenticular masses of laminated fine sand and gray clay ranging from 6 inches to 2 feet in thickness. Grades downward into bed 3.....	24
3. Cross-bedded very fine sand containing much muscovite, some biotite, and glauconite; interbedded with gray sandy clay.....	15
Cottondale formation	
2. Light gray to dark gray massive carbonaceous waxy clay containing lignitized twigs in some layers.....	18
1. Light red micaceous fine sand containing a few thin clay beds which weather light gray and lavender; irregular platy ferruginous sandstone layers cutting across bedding; grades downward into yellow loose coarsely cross-bedded medium to coarse sand, which becomes coarser with depth, and contains white clay and muscovite grains, clay flakes, thin beds, of silty clay, thin stringers of disc-shaped pebbles of quartz, quartzite, and a little sub-rounded chert. To bottom of valley.....	40

Northwest of Tuscaloosa, in the Samantha Quadrangle, the Cottondale formation is about 100 feet thick and composed chiefly of sand. The formation is well exposed about $11\frac{1}{2}$ miles northwest of Tuscaloosa along U. S. Highway 43 (Sec. 5, T. 20 S., R. 10 W.) where sandstone of the Pottsville formation is overlain by the Cottondale consisting of 3 to 6 feet of gravel, above which is about 40 feet of typical cross-bedded sand containing scattered pebbles.

Eighty feet of interbedded sand, silt, and gray and purple clay rests on an irregular surface of Pottsville near the old Tuscaloosa-Fayette road, 21 miles northwest of Tuscaloosa just east of Friendship Church on a long east-facing slope (W. $\frac{1}{2}$ Sec. 26, E. edge Sec. 27, T. 18 S., R. 11 W.). Here most of the contacts within the Cottondale are sharp and irregular, indicating alternate deposition and scouring.

In the Cottondale Quadrangle the formation seems to thicken down dip. Outcrops and coal test holes near Duncanville indicate a thickness of about 125 feet, whereas exposures 8 miles up the dip show about 50 feet or less of the Cottondale formation.

EOLINE FORMATION

The Eoline formation, named for excellent exposures in cuts along Alabama Highway 6, about 30 miles southeast of Tuscaloosa, and $1\frac{1}{2}$ miles east of the community of Eoline (variously pronounced, but probably best with a short i and accented on the E) is here defined as the marine beds between the apparently non-marine Cottondale and Coker formations.

PRE-SELMA STRATIGRAPHY OF WESTERN ALABAMA 195

SECTION EXPOSED ON WEST-FACING SLOPE ON ALABAMA HIGHWAY 6, 1½ MILES
SOUTHEAST OF EOLINE, BIBB COUNTY, ALABAMA

	Feet
Coker formation	
White friable clayey, micaceous sand; present in channel incised into Eoline formation.	
Maximum.....	8
Eoline formation	
Laminated gray fissile carbonaceous clay having partings of very fine sand containing pale flaky glauconite grains; landslips common in this material on slopes on both sides of highway. Exposed to top of hill.....	35
Concealed.....	20
Red coarsely cross-bedded glauconitic fine sand; a few thin beds of carbonaceous clay. Exposed to top of cut.....	10
Gray carbonaceous clay thinly interbedded with glauconitic very fine sand and silt; minor lenses of cross-bedded glauconitic sand.....	8
Cross-bedded glauconitic fine sand containing muscovite, red quartz, grains of dark minerals, and thin lenses of clay; lower half coarser and only sparsely glauconitic.....	22
Thin-bedded carbonaceous clay and fine sand, in upper half containing many yellow, flaky to oval very fine grains of glauconite; underlain by yellow medium sand containing a few grains of rounded green glauconite, muscovite, chert, rounded quartz, and concentrations of dark minerals.....	4
Concealed.....	3
Cottondale formation	
Massive and cross-bedded medium to coarse sand, containing muscovite, dark mineral grains, a few light green rounded questionable glauconite grains, some subangular, elongate pebbles of chert 1 inch long; smaller flattened, discoid and oval quartz pebbles; a few thin beds of light gray clay and some clay pebbles.....	15

In fresh exposures the Eoline formation consists chiefly of finely glauconitic fine to medium sand and laminated dark gray clay (Fig. 3); in weathered exposures the sand exhibits a rusty red color unlike other reds commonly seen in the Tuscaloosa deposits, and the clays are light gray to dark gray. In all but the freshest exposures the glauconite is difficult to recognize, partly because of its small size (commonly less than 0.5 mm.) and partly because it seems to be a type that weathers readily from its olive-green color when fresh to pale green or light yellow. Regardless of color, however, the glauconite may commonly be recognized, with the aid of a strong hand lens, by characteristic botryoidal and capsule shapes. Experience also shows that the formation may be readily recognized in most outcrops by a characteristic alternation of thin beds of clay, silt, and rippled sand. Its maximum outcrop thickness is about 125 feet, though locally it is somewhat thinner because its upper surface is incised by Coker channels.

Fossil leaf fragments are common in clay, especially near the top of the Eoline formation, and locally there is much lignitized wood ranging in size from tiny chips to logs a foot in diameter. Borings of *Halymenites major* Lesquereux are present locally in the upper part, as are other borings which do not show the diagnostic nodes of *H. major*. Obscure prints of mollusks found by Stephenson many years ago in Chilton County, about 4 miles northeast of Maplesville,¹⁴ and

¹⁴ L. W. Stephenson and W. H. Monroe, "Stratigraphy of Upper Cretaceous Series in Mississippi and Alabama," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 12 (December, 1938), p. 1653.

by the present writers a few miles farther northeast are the only invertebrate remains thus far found on the outcrop. Stephenson has recognized *Ostrea* sp., *Brachidontes* sp., *Glycymeris*?, and *Corbicula* sp. from a collection obtained from two 3-foot beds of silty clay separated by 11 feet of sand and clay, near the top of the Eoline formation exposed in road cuts in the NE. $\frac{1}{4}$ of Sec. 5, T. 21 N., R. 13 E., $\frac{1}{4}$ mile west of Isabella School.

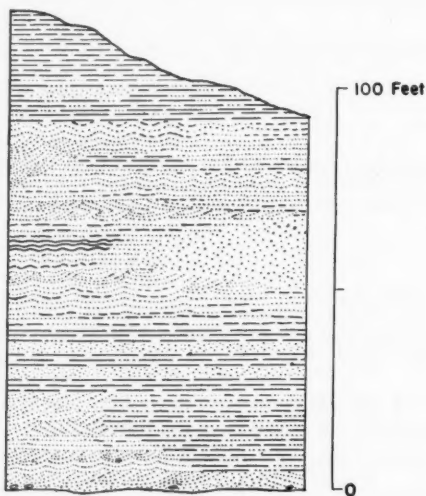


FIG. 3.—Generalized section of Eoline formation.

The basal contact of the Eoline formation at a few places is sharp and slightly undulating, apparently a minor unconformity. At a very few places the contact is immediately overlain by a bed less than an inch thick having $\frac{1}{4}$ -inch pebbles but at many places where exposures are reasonably good it is difficult or impossible to pick a contact. At some places several feet of laminated clay containing questionable glauconite in sand stringers lies at or close to the contact. Where such clay rests on massive clay, the contact is placed at the top of the massive clay, but as laminated clay is also known both in the lower part of the Eoline and in the Cottdale formation its presence between sand of the Cottdale and glauconitic sand of the Eoline causes doubts and probably has led to some inconsistencies in mapping. At other places, non-glauconitic sand seems to grade upward into glauconitic sand. In such areas, however, the doubtful zone is only about 10 feet thick and makes little difference in the areal pattern. The abundant outcrops of such doubtful beds suggest a transition from Cottdale to Eoline, with only minor local breaks in deposition.

No definite sequence of individual sand and clay beds has been discovered within the Eoline formation except that in general the lower half is more sandy and the upper half more clayey. At most good exposures the upper 20 to 30 feet is predominantly laminated clay which locally contains leaves, lignitized wood, scattered amber, and concretions of marcasite and massive siderite. Locally the siderite concretions are so abundant and of such size and shape as to have the appearance of a conglomerate bed several inches thick. It was from the laminated clay in the upper Eoline that Berry,¹⁵ obtained a small flora at the Snow Plantation and the Sanders Ferry Bluff (both probably in the S. $\frac{1}{2}$ of Sec. 28, T. 21 S., R. 11 W., near Twelve Mile Rock). From Berry's published sections, adapted from the notes of L. W. Stephenson, it is clear that the leaves are from the uppermost Eoline, directly below a massive clay now considered Coker.

At a few places the laminated clay and fine sand of the Eoline formation are highly contorted, broken, and seemingly rolled up. Submarine slipping along the bedding might explain this feature.

Regionally the marine characteristics of the Eoline formation, in the area thus far studied, are more easily recognized in the more eastern and in downdip exposures, where glauconite, *Halymenites*, and finely rippled bedding are all more strikingly developed. The updip exposures and those to the northwest are less glauconitic, have few or no *Halymenites*, contain coarser sand, and commonly exhibit light purple and pink coloration. Although the formation has not yet been mapped north of the Tuscaloosa-Fayette County line, it has been recognized as far north as Guin, Marion County, where characteristic rippled laminated silty sand has been seen. Eastward it has been traced in reconnaissance to Clanton, Chilton County. The formation is thus known to extend on the outcrop at least from Marion County to Chilton County, a distance of more than 100 miles.

In the middle of the Eoline formation, northwest of Tuscaloosa, a coarser sand, only slightly, if at all, glauconitic, intervenes between the characteristically thin-bedded clay and glauconitic rippled fine sand which are present at or near the top and bottom of the formation. A good example of this is about $7\frac{1}{4}$ miles northwest of Tuscaloosa on the Moores Bridge Road where cuts for a new location of the road (SW. $\frac{1}{4}$ Sec. 19, T. 20 S., R. 10 W.) show about 100 feet of Eoline containing 15 to 20 feet of doubtfully glauconitic coarser sand just below the middle.

COKER FORMATION

The Coker formation is named for excellent exposures on the west valley wall of Warrior River about 3 miles south of the village of Coker, which is about 7 miles west of Tuscaloosa on the Columbus Highway (U.S. 82). The section on the road east from Spring Hill School in Secs. 21 and 22, T. 21 S., R. 11 W., is

¹⁵ E. W. Berry, "Upper Cretaceous Floras of the Eastern Gulf Region in Tennessee, Mississippi, Alabama and Georgia," *U. S. Geol. Survey Prof. Paper 112* (1919), pp. 19-20.

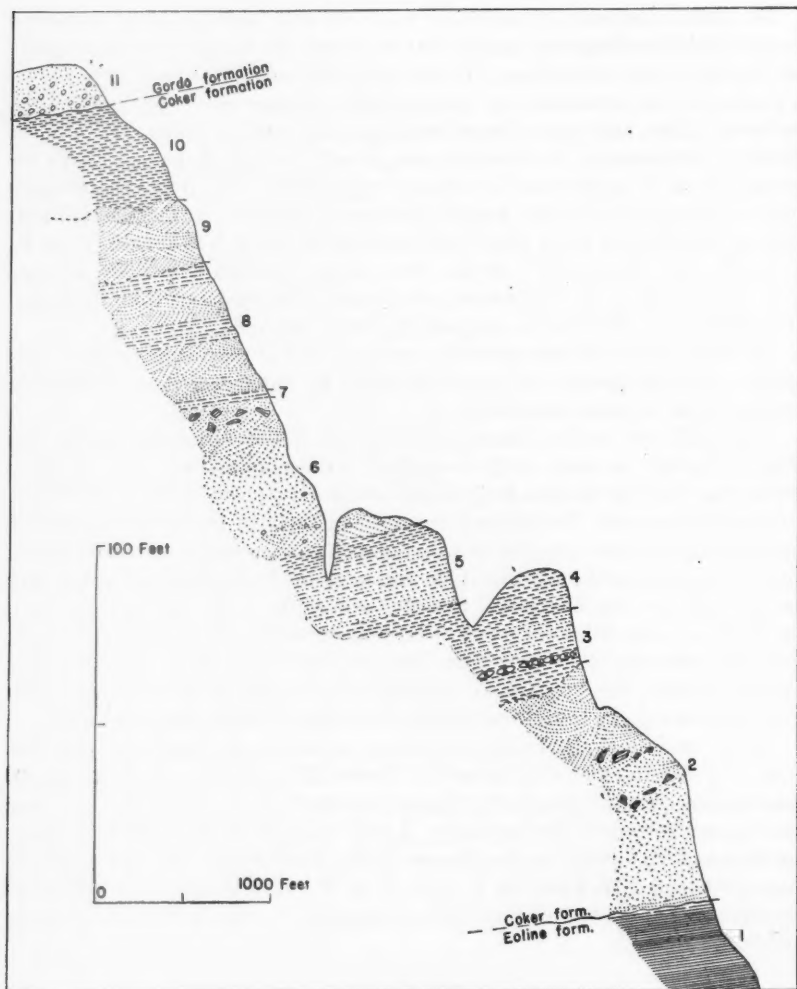


FIG. 4.—Profile section of type locality of Coker formation, 3 miles south of Coker, Alabama.

proposed as a type locality where both the top and bottom contacts are well exposed (Fig. 4). In the following section the contacts of the beds are so irregular that only average thicknesses are given.

SECTION ON HILL HALF A MILE EAST OF SPRING HILL SCHOOL

(Numbers refer to beds in graphic section, Fig. 4)

Gordo formation	Feet
11. Light red gravelly sand, gravel chiefly of chert but some quartz present; to top of hill.	13
<i>Unconformity</i>	
Coker formation	
10. Light gray silty clay, deeply mottled with light red, maroon and yellow in upper 5 feet; highly irregular base marked by platy ferruginous layers.	28
9. Light tan to white cross-bedded micaceous fine to medium sand containing clay chips, red quartz, smoky quartz, and black mineral grains.	20
8. Yellow, light red, and lavender mottled silty clay containing muscovite and some chlorite; irregularly interbedded with thick beds of very light gray silt and very fine sand that show faint layering and cross bedding.	12
7. Lens of mottled orange-red and gray micaceous and chloritic silty clay.	3
6. Medium-grained sand containing angular to rounded grains of quartz, scattered muscovite, dark mineral grains and clay chips; grading downward into medium to coarse sand containing a few small chert and quartz pebbles.	45
5. Gray silty clay mottled with red and purple, grading downward into fine sand containing muscovite, red quartz, chlorite, concentrations of white and dark-colored minerals, and a few rounded chert grains; platy and tubular masses of ferruginous sandstone near top.	25
4. Silty clay mostly light gray near top and variegated below, weathering to purple mottled with yellow, tan, and red; grading downward into clays below.	15
3. Dark purplish gray clay containing limonite spherules (weathered siderite); grading downward into light gray waxy clay that contains selenite crystals as much as 2 inches long in joints, cracks, and bedding planes; about 10 feet below the top as much as half the bed made up of spherulitic limonite; very irregular base.	15-20
2. Gray cross-bedded micaceous and chloritic very fine carbonaceous sand grading downward into coarser sand containing many angular and rounded blocks of carbonaceous clay and finely laminated sand; lower 2 feet laminated micaceous, carbonaceous sand containing ferruginous layers.	65-70
<i>Unconformity</i>	
Eoline formation	
1. Laminated carbonaceous and micaceous light tan to dark gray clay having partings of very fine sand and silt which are micaceous, chloritic, and sparingly glauconitic.	25

The laminated clays in this section assigned to the Eoline formation (bed 1) are apparently the continuation of the beds from which Berry collected plants at the Snow Plantation and Sanders Ferry Bluff, both a mile southwest. The highly cross-bedded sand of bed 2 is missing at Berry's localities, where massive clay of the Coker formation rests on the laminated clay of the Eoline. The contact between the two types of clay is well displayed at Robinson Bend (SE. $\frac{1}{4}$ Sec. 5, T. 22 S., R. 11 W.), where it is sharp and undulating and has a relief of about 10 feet. The alternate presence of clay and sand at the base of the Coker at first caused considerable confusion, but it is now clear that the Coker is everywhere unconformable on the Eoline. At some places the sand fills channels scoured as much as 40 feet into the underlying Eoline. *Preliminary Map 37* of the Oil and Gas Series shows contours drawn on such a channel in the Cottondale Quadrangle. The basal contact of the Coker in this channel is well exposed on the Cottondale-Big Sandy Spring road (W. edge Sec. 8, T. 22 S., R. 8 W.), where the contact slopes northwest 15° - 20° for a vertical distance of about 8 feet.

The nodules of granular siderite in bed 3 are a notable and characteristic feature which is found at approximately the same stratigraphic position at many places throughout the area thus far mapped.

Chert pebbles such as are sparsely present near the middle of the formation in bed 6 are locally more abundant east of the village of Buhl on the Columbus Highway in Sec. 31, T. 20 S., R. 11 W., and Sec. 36, T. 20 S., R. 12 W. Such gravel in the Coker formation is rare except in a few isolated localities, probably related to drainage systems during the Cretaceous period, and due care in field mapping will prevent miscorrelation with the Gordo formation. The sand and gravel beds in the Coker are distinctly lighter in color in fresh or weathered exposures than are similar beds in the Gordo formation.

The only bentonite thus far found in the Tuscaloosa group in Alabama is near the base of the Coker formation $\frac{1}{2}$ mile northeast of the type locality (NW. $\frac{1}{4}$ Sec. 22, T. 21 S., R. 11 W.), where one and probably two 2-foot beds are exposed. A few pebbles of impure bentonite at the same stratigraphic position are present in the type section near the bottom of bed 2.

The Coker formation is easily recognized throughout the area where it has been mapped because of the consistently light-colored sand, the widespread occurrence of the concretions of granular siderite, the strikingly cross-bedded micaceous channel sands, and the sharp upper and lower contacts. It has been recognized as far north as Hamilton, Marion County, and as far east as Maplesville, Chilton County, an airline distance of about 115 miles. No marked departures in thickness from that of about 230 feet at the type locality have been observed in the region thus far studied in detail.

GORDO FORMATION

The Gordo formation is the principal gravel-bearing unit of the Tuscaloosa group. It consists of lenticular beds of gravel, sand, and clay which rest unconformably on the Coker formation and are overlain unconformably by the marine McShan formation. The town of Gordo, Pickens County, is near the middle of the formation and typical exposures may be seen along any of the near-by roads, especially along the Tuscaloosa-Columbus highway (U. S. 82) for several miles on either side of the town. An exposure of the middle third of the formation showing typical gravelly sand and mottled clay on the south-facing slope of Little Bear Creek Valley (Sec. 20, T. 20 S., R. 13 W.) 2 miles southwest of Gordo is designated the type locality.

SECTION OF GORDO FORMATION ON SOUTH-FACING SLOPE OF LITTLE BEAR CREEK VALLEY

	<i>Feet</i>
Highly cross-bedded fine to coarse poorly assorted finely micaceous sand; coarse chert gravel in lower part; a little mottled clayey sand	47
Gray silty clay strongly mottled with purple and red; thick lenses of tan to gray compact slightly gravelly sand	13
Compact tan and light gray cross-bedded poorly assorted fine to coarse gravelly sand	32

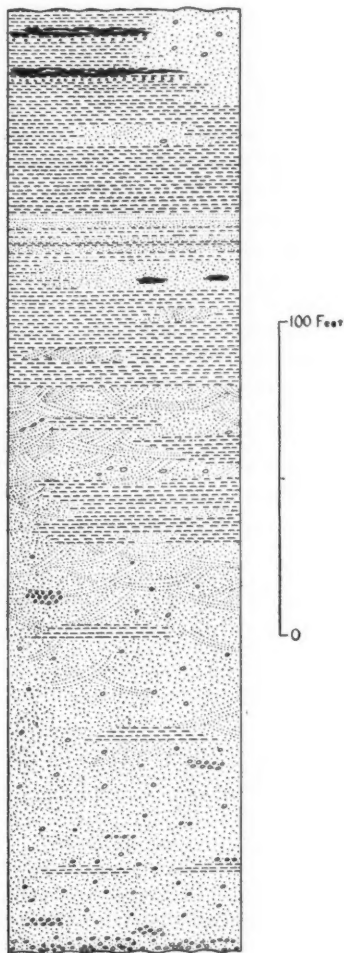


FIG. 5.—Generalized section of Gordo formation.

At most outcrops of the basal contact of the Gordo formation coarse gravelly sand or sandy gravel rests sharply on clay or fine sand of the Coker formation. A prominent layer of ferruginous sandstone at the base of the Gordo makes this the easiest of the pre-Selma contacts to map.

The Gordo formation may be divided roughly into two members, a lower one consisting of about 130 feet of more or less gravelly sand containing thin lenses of mottled purple and gray clay and light-gray somewhat carbonaceous silty clay,

and an upper member consisting of about 170 feet of lenticular mottled clay, carbonaceous clay, and strongly cross-bedded sand, locally gravelly (Fig. 5). The combined thickness of 300 feet appears to be constant throughout Pickens, Tuscaloosa, and Greene counties.

The gravel consists predominantly of chert pebbles derived in large part from the Mississippian limestones of northern Alabama and Tennessee. Locally, however, as many as one fourth of the pebbles are quartz, perhaps derived from the much nearer conglomerates of the Pottsville formation. The gravelly sand is easily eroded, so that near the larger streams gullies are common in the lower part of the formation, thus affording abundant outcrops of the basal contact of the formation. Some of the best of these exposures are in the many gullies on the west wall of the Warrior River valley 3 to 7 miles south of Coker.

Although the Gordo formation is decidedly lenticular it was found possible to map a contact of the two members because a bed of mottled purple and gray clay as thick as 20 feet is commonly present at the base of the upper member. This clay bed is absent locally, but is present at enough places to be of use in determining regional structure. The clay is overlain by lenticular cross-bedded fine micaceous yellow to light brown sand that locally contains much chert gravel—more gravel at some places than the underlying lower member. This sand bed is overlain by alternating thick layers or lenses of mottled clay and cross-bedded sand, some of which contains much chert gravel, nearly to the top of the formation. Locally the uppermost part of the formation consists of very carbonaceous clay immediately underlain by siderite spherules disseminated in clay—the “ankerite” grains of many subsurface geologists. At a few places the top of the formation consists of gravelly sand differentiated with difficulty from the overlying McShan formation.

The upper part of the Gordo formation is typically developed in the following section exposed in road cuts in the NW. $\frac{1}{4}$ of Sec. 17, T. 22 S., R. 13 W., Pickens County.

SECTION AT PLEASANT GROVE

	<i>Feet</i>
McShan formation	
Somewhat gravelly, slightly glauconitic sand in lower part, shaly sand in upper part	11
Interbedded slightly glauconitic fine sand and silty, sandy finely laminated clay; sharp contact at base marked by ironstone	16
<i>Unconformity</i>	
Gordo formation	
Dark brownish gray carbonaceous clay	8
Yellow clay having cavities formerly filled by siderite, grading upward into clay containing abundant siderite spherules	2

Farther down hill at this exposure is characteristic gray clay mottled with purple.

The Gordo formation can be distinguished from the underlying Coker not only by the sharp unconformable contact, but by its consistently darker and more reddish sands and by a rich purple color in the clay mottling which contrasts

mined extensively in the Iuka area in Tishomingo County, Mississippi. Earlier work has shown that in northern Tishomingo County the Gordo is overlapped by the Eutaw formation (the McShan being overlapped somewhat farther south), which from there for some distance north rests directly on the Paleozoic.

MC SHAN FORMATION

The McShan formation formerly was included in the Eutaw formation in Alabama and in the Tuscaloosa formation in Mississippi. It consists of marine sand and clay that rest unconformably on the continental Gordo formation and that are overlain unconformably by the marine Eutaw formation. A continuous series of road cuts near the middle of the formation on the Tuscaloosa-Columbus highway (U. S. 82) in Secs. 17 and 18, T. 19 S., R. 15 W., $1\frac{1}{2}$ miles north of the village of McShan, Pickens County, has been selected as the type locality of the formation. The beds in this section are more or less lenticular and intergradational, but the following is a generalized description of the exposures.

SECTION OF MC SHAN FORMATION ON U. S. HIGHWAY 82, $1\frac{1}{2}$ MILES NORTH OF MC SHAN

	<i>Feet</i>
Red sandy soil.....	6
Thin-bedded rippled finely glauconitic, finely micaceous very fine sand having gray clay stringers along bedding planes; locally merging laterally into laminated gray silty clay having partings of very fine sand, cross-bedded in lower part.....	48
Light gray very finely sandy and silty clay, some of which is laminated with very fine sand.....	11
Laminated and rippled mealy, very fine sand containing sparse pale-amber glauconite; silicified log about 7 feet above base.....	23
Laminated dark gray carbonaceous clay having partings of white very fine sand; lighter and more sandy in lower part.....	21
Cross-bedded sparingly glauconitic fine to medium sand, locally ferruginous; many chert pebbles in lower part; a few thin beds of mealy slightly glauconitic, silty very fine sand.....	35
Concealed to foot of hill.....	5

All but the upper 50 feet or less of the formation is exposed in a long series of cuts on a local road on the east side of Lubbub Creek Valley 1 to 2 miles east of Carrollton, Pickens County. Thicknesses given in the following composite section of this locality were obtained by an altimeter.

SECTION EAST OF CARROLLTON

	<i>Feet</i>
McShan formation	
Interbedded light gray laminated clay and cross-bedded light red and yellow slightly glauconitic fine sand.....	14
Cross-bedded mealy micaceous yellow very fine sand containing pale yellow glauconite; gray clay along bedding planes.....	16
Sand like above interlaminated with light gray and pink silty clay; a few lenses of slightly glauconitic fine sand.....	33
Light gray shale having partings of very fine white sand; a few interbedded layers of finely glauconitic fine sand; more sandy, silty, and carbonaceous in lower part; 1-inch ironstone layer at base.....	20
Finely cross-bedded to laminated and rippled slightly micaceous, glauconitic very fine sand; glauconite very fine and pale green to amber; some clay-breccia; stringers of gray clay along bedding planes; lower part more strongly cross-bedded.....	53
Laminated and rippled slightly carbonaceous, clayey, finely micaceous, very finely glauconitic, silty very fine sand grading downward into yellow cross-bedded sand with a few clay balls.....	12
Concealed.....	8

Interbedded gray clay and well rounded fine quartz sand, locally very ferruginous.....	7
Concealed.....	8
Laminated and rippled clayey, silty, finely micaceous, finely glauconitic very fine sand.....	15
Conglomeratic ironstone containing clay balls and thin beds of laminated very fine sand.....	3
<i>Unconformity</i>	
Gordo formation	
Massive gray silty, sandy clay to floodplain.....	7

An exceptional feature of the basal part of the McShan, not shown in the preceding section, is that the basal bed does not necessarily contain the principal conglomerate of the formation. At many places, especially in the Warrior River Valley near the village of Ralph, the basal 6 to 20 feet of the McShan formation, consisting of laminated and rippled very fine-grained glauconitic sand, and having a few small pebbles in its lower inch, lies abruptly on sand and clay of the Gordo formation and is in turn sharply overlain by as much as 40 feet of gravelly sand. There is no doubt that the base of this gravel is everywhere higher than the base of the formation, as no glauconite has been found in the Gordo, as every outcrop of the contact exhibits a sharp break between the non-glauconitic Gordo and the overlying glauconitic thin-bedded material of the McShan, and as a few pebbles can be found in the basal inch of the glauconitic beds.

The characteristic glauconite of the McShan formation is the pale soft easily weathered type like that previously described from the Eoline formation. It is markedly different from the glauconite of the overlying Eutaw formation, which is much coarser and retains its green color on slight weathering, and which on deep weathering produces a dark red soil, whereas the glauconite of the McShan turns yellow on weathering and commonly produces light red soil.

No granular siderite or siderite spherules have been found in the McShan, but small well rounded flattened pebbles of concretionary earthy siderite are common particularly in the middle and upper parts of the formation.

Within the area in which the McShan formation has been mapped in detail it appears to be about 240 feet thick in the Warrior River Valley but to be thinner toward the northwest. No direct measurements of its thickness have been possible, but by projection of dips based on elevations of upper and lower contacts, it appears to be about 225 feet thick in Sipsey River Valley and about 200 feet thick in the type area along U. S. Highway 82. Still farther north it thins rapidly and on U. S. Highway 78 on the hill west of Chubby Creek, 7 miles east of Fulton in Itawamba County, Mississippi, the formation is only 57 feet thick as shown in Figure 7 and in the following section.

SECTION IN EAST-FACING SLOPE OF CHUBBY CREEK VALLEY, U. S. HIGHWAY 78,
7 MILES EAST OF FULTON, ITAWAMBA COUNTY, MISSISSIPPI
(Numbers refer to beds in graphic section, Fig. 7)

Eutaw formation	Feet
14. Red cross-bedded coarsely glauconitic fine to medium sand containing a little muscovite; base marked by a 1- to 1½-foot layer of sand containing fine chert gravel and much silicified wood, overlain by a 1- to 2-foot layer of irregular tubular ferruginous sandstone; to top of cut.....	14

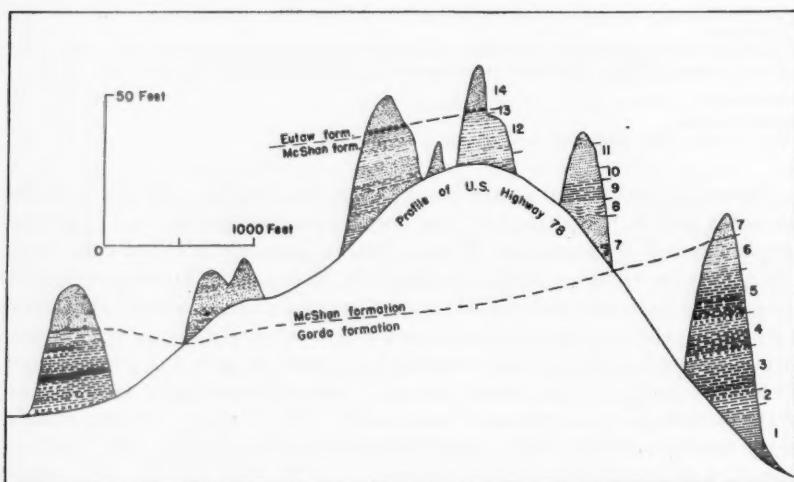


FIG. 7.—Profile section along U. S. Highway 78, 7 miles east of Fulton, Mississippi.

*Unconformity**McShan formation*

- | | |
|--|-------|
| 13. Lenticular yellow and white massive to faintly laminated slightly glauconitic very fine sand; a few clay pebbles and stringers..... | 1-3 |
| 12. Interlaminated light to dark gray very fine sand and silty clay; in beds 1 to 3 feet thick between which are beds of massive carbonaceous clay containing minor amounts of sand..... | 13-15 |
| 11. Laminated mealy glauconitic, micaceous sand; some lenses of clay flakes..... | 8 |
| 10. Light gray laminated and rippled very fine sand and sandy silt..... | 4 |
| 9. Dark gray laminated carbonaceous clay having partings of very fine sand..... | 6 |
| 8. Laminated and rippled silty very fine sand; minor amounts of carbonaceous clay..... | 6 |
| 7. Cross-bedded fine to medium sand containing pale glauconite grains, much clay conglomerate, and a few thin beds of carbonaceous clay; in basal 9 feet thin plates of ferruginous sandstone; contact with the underlying formation indistinct..... | 17 |

*Unconformity**Gordo formation*

- | | |
|---|----|
| 6. Light bluish gray massive very fine sandy silt, slightly indurated; faintly laminated carbonaceous clay near top; much thin ferruginous sandstone at and below the middle; persistent layer of ferruginous sandstone 1 inch thick at base..... | 11 |
| 5. Gray carbonaceous silty clay grading downward to dark gray and black waxy clay; a lignite zone about 5 feet below top..... | 15 |
| 4. Light gray clay, stained yellow along joints; many limonite spherules near top; grading down into dark gray carbonaceous clay 3 feet below the limonite zone..... | 10 |
| 3. Light gray to yellow, iron-stained plastic clay, containing many limonite spherules concentrated in nodules near top..... | 12 |
| 2. Gray lignitic clay containing many plant fragments and siderite spherules near top; lighter bluish gray below..... | 5 |
| 1. Gray laminated carbonaceous clay and very fine sand; much iron staining..... | 22 |

The only fossils thus far found in the McShan formation, other than borings of *Halymenites major* Lesquereux, is a print of *Breviarca* sp., noted by L. W. Stephenson in a clay now considered to be McShan at Browns Bluff (Sec. 30,

T. 22 N., R. 3 E.) on Warrior River, Hale County; fossil plants collected by Berry¹⁶ from laminated sand and clay near the base of the McShan in gullies near Havana, Hale County; and silicified and lignitized wood.

EUTAW FORMATION

The Eutaw formation was originally named by Hilgard¹⁷ for the strata between the Carboniferous and his Tombigbee sand group. Smith and Johnson¹⁸ in 1887 restricted the Eutaw by removing from it their Tuscaloosa formation, but they included Hilgard's Tombigbee sand in the upper part of their Eutaw. Later Stephenson¹⁹ formally recognized the Tombigbee sand as an upper member of the Eutaw formation. In the present paper it is proposed to restrict the Eutaw further by differentiating a lower unit of formational rank, the McShan, from which the restricted Eutaw is separated by an unconformity of regional extent.

Hilgard designated no type locality other than the town of Eutaw, Greene County. For the benefit of those who like to visit and collect from typical exposures, it may be noted that the uppermost part of the Eutaw and the contact with the overlying Mooreville chalk of the Selma group are well exposed $4\frac{1}{2}$ miles south of Eutaw at Choctaw Bluff (Sec. 26, T. 21 N., R. 2 E.) on the Warrior River in Greene County, where 11 feet of the Tombigbee sand member of the Eutaw is exposed at normal low water. An excellent section of the upper part of the main body of the Eutaw formation is exposed in cuts on an abandoned road $\frac{1}{2}$ mile due north of the courthouse at Eutaw.

SECTION HALF A MILE DUE NORTH OF EUTAW

	Feet
Soil: Red clayey sand.....	10
Eutaw formation (Tombigbee sand member?):	
Gray and reddish tan highly glauconitic, clayey sand, weakly bedded, filled with borings including those of <i>Halymenites major</i> ; abundant flakes of gray clay in lower 4 feet.....	11
Eutaw formation (typical)	
Thin-bedded highly glauconitic sand containing abundant laminae of flaky gray clay; grading downward into highly cross-bedded very glauconitic sand having clay stringers along cross beds; light and dark gray clayey shale containing interbeds of very glauconitic sand in lower part.....	35
Weakly bedded to massive light tannish gray sand filled with borings in upper 15 feet; bedding and cross-bedding more pronounced in lower part of section; grading downward into slightly shaly sand.....	55

The base of this section is approximately 40 feet above the base of the Eutaw formation.

¹⁶ E. W. Berry, "Upper Cretaceous Floras of the Eastern Gulf Region in Tennessee, Mississippi, Alabama, and Georgia," *U. S. Geol. Survey Prof. Paper 112* (1912), p. 33.

¹⁷ E. W. Hilgard, "Report on the Geology and Agriculture of Mississippi," Jackson (1860), p. 61.

¹⁸ E. A. Smith and L. C. Johnson, "Tertiary and Cretaceous Strata of the Tuscaloosa, Tombigbee, and Alabama Rivers," *U. S. Geol. Survey Bull. 43* (1887), p. 98.

¹⁹ L. W. Stephenson, "Cretaceous Deposits of the Eastern Gulf Region," *U. S. Geol. Survey Prof. Paper 81* (1914), p. 14.

The Eutaw formation rests on the McShan formation unconformably and apparently overlaps the McShan toward the north. The actual contact, however, is somewhat difficult to map because the two formations are made up largely of glauconitic sand and shale of similar aspect. In the Warrior River Valley the basal bed of the Eutaw consists of light gray massive glauconitic, clayey sand,

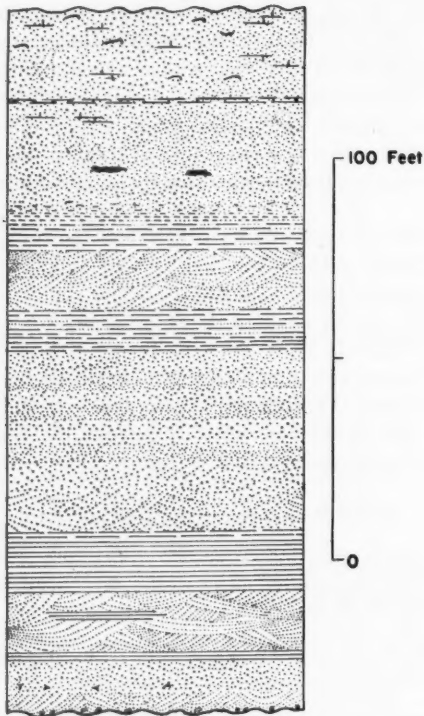


FIG. 8.—Generalized section of Eutaw formation.

more or less perforated by borings, and similar massive gray sand of this type is common throughout the Eutaw, but has not been seen in the McShan. These beds of massive sand resemble closely the Tombigbee sand at the top of the formation, but at most places the basal bed contains phosphatic nodules, fragments of charred wood, and a few chert pebbles whose edges are well rounded, and locally the bed contains shark teeth—a diagnostic feature, as such teeth have thus far been found in no other beds of the McShan or in the Eutaw below the Tombigbee sand member.

At Starlight School (E. edge, SE. $\frac{1}{4}$ Sec. 1, T. 22 N., R. 2 E.) where the contact has about 2 feet of relief, L. W. Stephenson has recently recognized prints of the following fossils from the basal bed of the Eutaw formation: *Nemodon* sp., *Ostrea* sp., *Exogyra* sp. (fine irregular costae), *Lima* sp., *Pholadomya* sp., shark teeth, and vertebrae.

Farther north the basal bed of the Eutaw formation is more commonly a highly cross-bedded coarsely glauconitic sand containing scattered chert pebbles and abundant small white specks, presumably chert. This sand is coarser than any sand in the upper part of the McShan formation and at all critical exposures the bed has been found by careful search. Chert gravel in the basal bed is more abundant in the northward extension of the formation, becoming abundant in Monroe County, Mississippi, and forming a true conglomerate about 2 feet thick in Itawamba County. In northern Mississippi the Eutaw formation overlaps both the McShan and the Gordo formations in Tishomingo County, Mississippi, and rests directly on Paleozoic rocks.

The earliest abundant Cretaceous invertebrate fossils known on the outcrop in the region under consideration are in the upper part of the Eutaw formation. At old Finches Ferry, Greene County, glauconitic sandstone of the Eutaw, probably less than 100 feet above the base of the formation, contains impressions of mollusks. Here Stephenson has recently recognized from a 1-foot ironstone bed at the top of the bluff impressions of *Ostrea battensis* Stephenson, a diagnostic fossil of the Eutaw formation in central Alabama. About 5 to 15 feet below are two other fossiliferous sandstone layers from which he has recognized *Barbatia* sp., *Cardium* (2 species), and *Pugnello* sp. Only in the Tombigbee sand member, however which constitutes the uppermost part of the formation, are fossil shells abundant.

Tombigbee sand member.—The upper part of the Eutaw formation consists of massive to weakly bedded light gray somewhat clayey, highly glauconitic sand containing abundant borings and, in the upper part, many molluscan shells. Stephenson and Monroe²⁰ list 14 species of pelecypods and 8 species of cephalopods from the Tombigbee in Mississippi. A few additional species have been found in Alabama, but in general the member is more fossiliferous in Mississippi.

The member varies considerably in thickness along the strike. In Monroe County, Mississippi, Stephenson and Monroe found 87 feet of Tombigbee, but farther south the member appears to be thinner. At Plymouth Bluff on Tombigbee River, 4 miles northwest of Columbus, Lowndes County, only 50 feet referable to the Tombigbee is visible, but here the base of the member is not exposed. Recent mapping shows that the member is less than 25 feet thick at Pickensville (Sec. 13, T. 21 S., R. 17 W.), Pickens County, Alabama. On the south side of the Sipsey River Valley (in Sec. 27, T. 24 N., R. 1 W.), Greene County, Alabama, no Tombigbee sand was found between typical shale of the

²⁰ L. W. Stephenson and W. H. Monroe, "The Upper Cretaceous Deposits," *Mississippi Geol. Survey Bull.* 40 (1940), p. 69.

Eutaw and the overlying Mooreville chalk. In the Warrior River Valley, however, the Tombigbee is again present and appears to be about 35 feet thick. The absence of the member may be due to overlap by the Mooreville or to contemporaneous deposition of different kinds of material along the strike.

Criteria for differentiating the McShan and Eutaw formations.—The McShan and Eutaw formations are very similar lithologically, for they were deposited under similar conditions and had approximately the same source of materials. Recent field work, however, has revealed a number of criteria for differentiating the two formations.

The surest method of differentiating the McShan and Eutaw formations is to find and recognize the unconformity which separates them. At places this is difficult because of extreme local lithologic variability of the two formations. Locally the upper beds of the McShan are sand, whereas the lower beds of the Eutaw are shale, but at such places the basal bed of the Eutaw commonly contains the diagnostic shark teeth or impressions of them. The basal bed also commonly contains a few chert pebbles and fragments of charred wood.

The glauconite in the McShan formation is nearly all pale and fine-grained whereas that in the Eutaw formation is commonly coarse and dark green. Locally the McShan contains some medium-grained glauconite, but this is not common. Likewise, many of the beds in the lower part of the Eutaw contain fine pale glauconite like that in the McShan, but invariably careful search of such material has revealed a few beds of coarse glauconite of the Eutaw type.

Shale is more common in the McShan formation than in the Eutaw and is commonly lighter colored and more plastic in the McShan, whereas the shale of the Eutaw is typically dark gray, compact, and hackly.

Gray massive clayey sand containing many borings and closely resembling the Tombigbee sand member, but in thinner beds, is common throughout the Eutaw, but is unknown in the McShan. Conversely, the McShan contains much highly cross-bedded yellow finely glauconitic sand of a type unknown in the Eutaw.

CORRELATION WITH SUBSURFACE BEDS IN MISSISSIPPI

Preliminary study of samples from a series of wells between Tuscaloosa County, Alabama, and Neshoba County, Mississippi (to be published as *Preliminary Oil and Gas Chart No. 20*) shows that the pre-Selma formations described above can readily be traced down the dip toward the oil fields of Mississippi. For precise correlation many more well samples must be studied, but in general the same sequence of rocks already described is encountered in wells.

Cottondale formation.—The sand facies of the Cottondale formation is encountered in most wells in Mississippi. In the subsurface the Cottondale appears to consist of a thick section of sand containing so few "breaks" that it is called the "massive sand" by many petroleum geologists. It is commonly medium to coarse, somewhat lignitic and sideritic near the top, and gravelly below. The sand grains are subangular to rounded but the pebbles are well rounded. Downdip wells show the sand to contain abundant chert and numerous red and yellow trans-

lucent quartz grains, and the gravel to be composed chiefly of chert; updip wells show the sand and gravel to be composed chiefly of quartz. The "massive sand" is overlain by 10 to 50 feet of massive gray carbonaceous clay containing siderite and siderite spherules. The formation appears to thicken downdip from the 100 feet or less on the outcrop to more than 300 feet in Neshoba County, Mississippi.

Eoline formation.—The Eoline formation presents a fairly regular lithologic sequence of carbonaceous shale and prominent zones of glauconitic sand. The upper part commonly consists of greenish gray carbonaceous clay, somewhat sandy, and in places mottled with red and reddish brown stains. Some of the shale is coarsely chloritic and sparsely glauconitic. Located at or near the top is a sandy zone locally glauconitic and calcareous, which is underlain by a series of thin beds of glauconitic sand and carbonaceous shale. Thicker beds of marine sand containing thick-shelled fossils are generally encountered 50 to 100 feet below the top of the formation. The Eoline thickens downdip from 110 or 120 feet in water wells near the outcrop to slightly more than 200 feet in Neshoba County.

Coker formation.—Resting sharply on the shale of the Eoline or "marine Tuscaloosa" is a thick section of massive to lenticular interbedded sand, gravelly sand, and red to pink, purple to lavender, and gray to greenish gray clay. The sand is loose and porous and the clay, in thinner beds than the sand, is in places lignitic. Siderite spherules are common but are most abundant near the base of the unit. Sideritic sand, some of which is made up of spherulitic pellets, is also present. The siderite is apparently similar to that of the small non-sandy siderite spherules found in the Cottondale and the upper Gordo, but has incorporated grains of sand during its formation. The formation is highly irregular both in composition and in thickness of individual beds. Clay predominates over sand in all wells, especially in the lower half of the formation, but in most wells there is a sand section 50 or more feet thick at the top and another, but thinner, bed at the base of the formation. The thickness of the whole formation ranges from 160 to 230 feet, somewhat less than that of the outcrop. The Coker was recognized by McGlothlin²¹ who designated it the "shale and sand section of the lower Tuscaloosa."

Gordo formation.—In many wells it is difficult to differentiate the Coker and Gordon formations because of their similarity in composition. In central Mississippi, however, and farther north, a bed of sand containing abundant chert gravel, designated by McGlothlin²² the "chicken-feed chert," marks the base of the Gordo. This gravelly sand and overlying less gravelly sand are somewhat thicker than the lower member of the Gordo on the surface, having a total thickness of 180 to 400 feet in most wells. Locally the sand has a few thin breaks of gray lignitic clay or mottled gray and red clay. The sand section is overlain by a section composed largely of massive clay, pale gray to nearly white but generally mottled

²¹ Tom McGlothlin, "General Geology of Mississippi," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28, No. 1 (January, 1944), pp. 40, 41.

²² Tom McGlothlin, *op. cit.*, Fig. 6.

with red or purple. This clay contains abundant siderite spherules, especially toward the top. The uppermost part of the clay section is so soft that it is easily mixed with drilling mud and is readily washed away in cleaning the sample. Its salmon-red color, however, and the presence of siderite spherules readily mark it as the top of the Gordo. Locally the massive clay contains a few beds of sand and considerable sandy clay. The total thickness of the Gordo in the wells studied to date is between 300 and 500 feet—somewhat thicker than the Gordo on the outcrop.

McShan and Eutaw formations.—Preliminary examination of samples from wells has not yet yielded information definitive enough to separate the McShan and Eutaw formations in wells. Tentatively the two formations may be differentiated by recognition about 150 feet below the base of the Mooreville chalk of a zone or a series of lenses of coarse sand containing a few pebbles. In many wells samples from this zone contain fish remains and phosphate, which suggest correlation with the shark-tooth bed that marks the base of the Eutaw on the outcrop.

The rocks below the phosphate bed consist of alternating sand and shale. Directly overlying the Gordo the basal sand of the McShan is recognizable in all wells and ranges from 20 to 60 feet in thickness. Shale is common in this unit, but the sand is coarse and glauconite is sparse and pale. A few chert pebbles are common at the base. Higher in the McShan are two other sand beds separated by shaly zones.

Above the basal phosphatic sand of the Eutaw, which in many of the wells examined is about 20 or 30 feet thick, is a section of about 100 feet of gray carbonaceous shale interbedded with fine glauconitic sand. This is overlain by massive glauconitic sand that is locally calcareous and indurated—the Tombigbee sand member. This sand is locally fossiliferous and contains minor zones of shaly and lignitic materials. It has a maximum thickness of 75 feet, but locally is as thin as 10 feet.

Throughout the McShan and Eutaw formations the shale is carbonaceous containing leaf prints and fragments of lignitized wood. Considerable massive lignite is present, associated with pyrite or massive siderite. The massive siderite although commonly hard, dark brown, and crystalline, is locally soft, somewhat mealy or clayey, and light brown. Siderite is also present as a cement which binds sand, lignite, and glauconite.

The thickness of the combined Eutaw and McShan formations ranges from 370 to more than 430 feet, thinning toward both the north and the west.

Resting sharply on the Tombigbee sand member of the Eutaw is a bed of hard chalky sandstone or sandy chalk containing much phosphatic material, referable to the Mooreville chalk. The sand consists chiefly of rounded quartz and coarse green glauconite. The phosphatic materials consist of nodular phosphatic rock and of large rounded fossil fragments, notably bones and teeth of fish or reptiles. This basal sandy chalk of the Mooreville is typically less than 10 feet thick, though locally it is as much as 25 feet thick.

STRATIGRAPHY OF UPPER NEHALEM RIVER BASIN, NORTHWESTERN OREGON*

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ABSTRACT

Tertiary sedimentary strata are well exposed in the upper Nehalem River basin. They have been known for many years to geologists interested in West Coast Tertiary marine deposits but until recently no systematic study of the stratigraphy of the region has been attempted.

The rock sequence of the upper Nehalem River basin is here divided into three distinct groups separated by unconformities. The oldest group, the Tillamook volcanic series (Eocene), forms rugged highlands in the southwestern part of the area and represents the core of the Coast Range geanticline. Bordering the Tillamook volcanic series is a belt of Tertiary sedimentary strata ranging in age from upper Eocene to possibly lower Miocene, constituting the second group. The third and youngest group is the Columbia River basalt, a sequence of lava flows of middle Miocene age. These flows cap hills along the east side of the area and form extensive uplands.

The sequence of Tertiary rocks lying between the Tillamook volcanic series and the Columbia River basalt consists of about 5,000 feet of gently warped marine and brackish-water clastic sedimentary beds which are of interest as a possible source of petroleum and natural gas. These beds, beginning with the oldest, are divided into four formations; Cowlitz, Keasey, Pittsburg Bluff, and Scappoose, and each is characterized by a distinct assemblage of fossils. The Cowlitz and Keasey formations, together, represent at least 2,700 feet of marine strata, variable in composition but dominantly shaly and tuffaceous. Mollusks and foraminifers characteristic of shallow to moderately deep water are fairly abundant. Overlying the Cowlitz and Keasey formations are approximately 2,300 feet of dominantly arenaceous, marine to brackish-water beds of the Pittsburg Bluff and Scappoose formations which contain near-shore megafaunas.

Each of the sedimentary formations represents an advance of the sea into embayments covering the area of the present upper Nehalem River basin. Into these embayments streams from the east brought the products of normal erosion as well as varying contributions of contemporaneous volcanic ash and lapilli.

INTRODUCTION

The marine Tertiary sedimentary strata in the upper part of the Nehalem River basin in northwestern Oregon have attracted the attention of geologists because of the excellent fossils. Two formations in the area—the Keasey and the Pittsburg Bluff—have been described by previous writers. At present they, together with other sedimentary beds, are of interest as a possible source of petroleum and natural gas.

Heavy winter rainfall in the upper Nehalem River area, combined with otherwise mild climate, is conducive to a luxuriant growth of vegetation. At one time the area was covered with virgin timber; now all but a few scattered stands of the original trees have been cut and a second growth of trees and thick underbrush covers most of the area. This vegetation and deep weathering obscure the nature of the underlying rocks and seriously hinder geologic work.

The Nehalem River heads in the hilly country forming the eastern part of the Coast Range of northwestern Oregon. The upper part of its basin includes parts of Clatsop, Columbia, Tillamook, and Washington counties, and is covered by

* Manuscript received, November 16, 1945.

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† Geologist, Geological Survey.

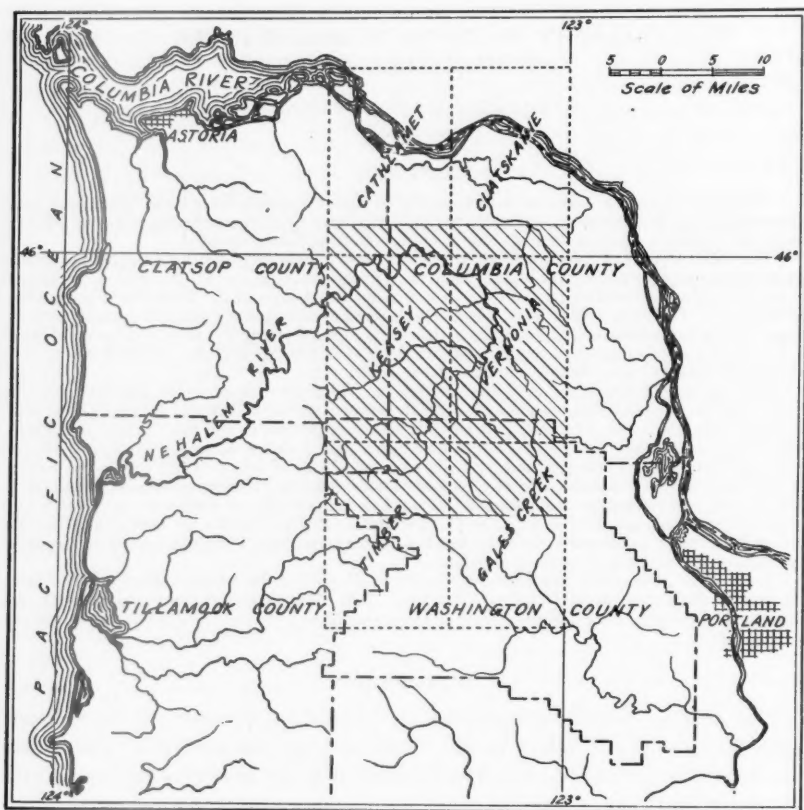


FIG. 1.—Index map of northwestern Oregon. Upper Nehalem River basin shown by shading; boundaries of quadrangle maps shown by dashed lines.

recently published topographic quadrangle maps of the Army Engineers as shown in Figure 1.

The Wolf Creek Highway crosses the southwestern part of the area and another surfaced highway follows the Nehalem River valley. These highways, together with connecting roads, make most parts of the area readily accessible.

Vernonia, whose population is approximately 1,600, is about 50 miles by road northwest of Portland and is the main town in the area. The United Railways, which is operated by the Southern Pacific Railroad, has its terminus at Vernonia and provides transportation facilities for lumbering, the principal industry of the region. The Tillamook branch of the Southern Pacific Railroad crosses the southern part of the area.

PHYSIOGRAPHY

The source of the Nehalem River is in an area of Eocene volcanic rocks in the core of the Coast Range, and in its circuitous course to the Pacific Ocean the river has cut through Miocene lava flows and has carved a valley in soft Tertiary sedimentary beds flanking the Eocene volcanic rocks.

The Miocene lavas have been completely removed west of the upper basin area, but north and east of the river they still form an extensive upland from 1,300 feet to 1,800 feet above sea-level. The altitude of this upland varies, owing to broad gentle folding of the lava.

The Eocene volcanic rocks west and southwest of the river form rugged highlands with peaks from 2,500 feet to 3,400 feet above sea-level.

In the area of sedimentary beds intervening between the two volcanic sequences, the river has cut its course to an altitude of approximately 450 feet at the western edge of the area, 550 feet at Vernonia, and 750 feet at Sunset Camp. Tributaries of the Nehalem River have reached well into the uplands, carving steep-sided valleys commonly 300 feet to 400 feet deep. The uplands commonly stand at altitudes ranging from 900 feet to 1,200 feet. Their uniformity in altitude suggests that the river formerly had a temporary base level about 400 feet higher than at present, and that rejuvenation has allowed the river and its tributaries to cut down rapidly, resulting in steep-sided valleys. Now the river has apparently reached another temporary base level and is forming flood plains.

HISTORICAL REVIEW

The earliest published reference to the sedimentary rocks of the upper Nehalem Valley was made in 1896 by Diller,¹ who described dark shales with abundant volcanic materials exposed in cliffs along Rock Creek from 6 to 10 miles above Vernonia. These rocks, which are now known as the Keasey formation, were considered by Diller to be Eocene on the basis of fossils identified by Dall. At a place referred to by Diller as Wilson Bluff 3 miles above Vernonia Diller found gray shales with concretions (Keasey formation), which were rightly considered to underlie sandstone at Pittsburg.

Diller described the fossiliferous sandstone bluff at Pittsburg and collected fossils which were studied by Dall. These fossils were at the time thought to be Oligocene, but in a latter paper Dall² described typical fossils from Pittsburg and regarded them as Eocene.

Washburne³ in his report on the oil possibilities of northwestern Oregon followed Dall in assigning the beds at Pittsburg Bluff to the Eocene.

¹ J. S. Diller, "Geological Reconnaissance in Northwestern Oregon," *U. S. Geol. Survey 17th Ann. Rept.* (1896), Pt. I.-C., pp. 458, 466.

² W. H. Dall, "Contributions to the Tertiary Paleontology of the Pacific Coast. Part 1, The Miocene of Astoria and Coos Bay, Oregon," *U. S. Geol. Survey Prof. Paper 59* (1909), p. 45.

³ C. W. Washburne, "Reconnaissance of the Geology and Oil Prospects of Northwestern Oregon," *U. S. Geol. Survey Bull. 590* (1914), p. 72.

In 1915 Clark⁴ compared the fauna from Pittsburg with other faunas from the west coast and stated that the fauna from Pittsburg "is everywhere very distinct both from that of the Eocene and from that of the typical Miocene."

Clark regarded the beds at Pittsburg Bluff as Oligocene, listed 21 species from that locality, and pointed out the relation of the assemblage to other Oligocene faunas from Washington and California.

Hertlein and Crickmay published a paper on the marine Tertiary of Oregon and Washington⁵ in 1925 in which they considered the beds at Pittsburg Bluff as undoubtedly Oligocene and suggested a lower Oligocene age for them.

Beginning in 1927, a series of papers by Schenck has materially advanced our understanding of the Tertiary sedimentary beds of northwestern Oregon. The terms Keasey shale and Pittsburg Bluff sandstone were introduced in a preliminary paper in 1927.⁶ In 1928 Schenck amplified his definition of the Keasey shale, saying it was employed

to designate the sandy tuffaceous, bluish fossiliferous shale that outcrops on the banks of Rock Creek, near Keasey . . .

The most characteristic exposures of the Keasey shale occur in the railroad cuts between stations named Tara and Keasey. The shale is generally black in color, compact, sandy, and fractured.⁷

In another paper he joined with Cushman in describing the Foraminifera of the Keasey formation and the Bassendorf formation.⁸ The two formations were considered to be the same age and were tentatively placed in the lower Oligocene.

In the course of subsequent field work Schenck verified his belief that the Keasey formation underlies the Pittsburg Bluff sandstone and he found Cowlitz (upper Eocene) beds beneath the Keasey formation. The following *Acila* biozones were established for the Oligocene.

Acila gettysburgensis (in part Miocene)
Acila shumardi
Acila nehaemensis (tentatively Oligocene).⁹

In 1935 Schenck and Kleinpell¹⁰ pointed out that nearly all the species of Foraminifera found in the Keasey and Bassendorf formations are also found in

⁴ B. L. Clark, "Occurrence of Oligocene in the Contra Costa Hills of Middle California," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 9 (1915), pp. 17-19.

⁵ L. G. Hertlein and C. H. Crickmay, "Marine Tertiary of Oregon and Washington," *Proc. Amer. Philos. Soc.*, Vol. 64, No. 2 (1925), p. 254.

⁶ H. G. Schenck, "Marine Oligocene of Oregon," *Univ. of California Pub., Bull. Dept. Geol. Sci.*, Vol. 16, No. 12 (1927), pp. 457, 458.

⁷ H. G. Schenck, "Stratigraphic Relations of Western Oregon Oligocene Formations," *ibid.*, Vol. 18, No. 1 (1928), pp. 35-39.

⁸ J. A. Cushman, and H. G. Schenck, "Two Foraminiferal Faunules from the Oregon Tertiary," *ibid.*, Vol. 17 (1928), pp. 305-24.

⁹ H. G. Schenck, "Nuculid Bivalves of the Genus *Acila*," *Geol. Soc. America Spec. Paper* 4 (1936), pp. 41-44.

¹⁰ H. G. Schenck, and R. M. Kleinpell, "Foraminifera from Gaviota Formation" (abstracts), *Pan-Amer. Geol.*, Vol. 64 (1935), p. 76; *Geol. Soc. America Proc. for 1935* (1936), p. 352.

the Gaviota formation of California. They regarded the Gaviota formation as upper Eocene.

In 1937 Weaver summarized existing knowledge and gave additional detailed information on the stratigraphy of northwestern Oregon. He gave an approximate thickness of 1,200 feet for the Keasey formation and listed some characteristic fossils.¹¹ The formation was divided into a lower dark-colored sandy shale member and an upper shaly sandstone member which comprised two-thirds of the formation. Weaver described the beds at Pittsburg Bluff and suggested that the name Pittsburg Bluff formation be extended to include not only the richly fossiliferous beds at Pittsburg but the entire middle Oligocene sequence in Columbia County.¹² He gave a thickness of 4,000 feet for these strata as exposed between Pittsburg and the town of Clatskanie at the north on the Columbia River.

In 1942 existing knowledge of the Tertiary megafaunas of Oregon and Washington was summarized by Weaver in an invaluable monograph in three volumes.¹³

Recently, an excellent paper by Durham appeared in which he divided the Oligocene of northwestern Washington into seven megafaunal zones.¹⁴ These zones are comparable with Schenck's biozones as follows.

<i>Echinophoria apta</i> zone	} <i>Acila gettysburgensis</i> biozone
<i>Echinophoria rex</i> zone	
<i>Turritella porterensis</i> zone	
<i>Turritella olympicensis</i> zone	} <i>Acila shumardi</i> biozone
<i>Molopophorus gabbi</i> zone	
<i>Molopophorus stephensoni</i> zone	} <i>Acila nehalemensis</i> biozone
" <i>Turricula columbiana</i> zone" (proposed tentatively)	

As will be indicated farther along, the "*Turricula columbiana* zone" is equivalent to only a small part of the *Acila nehalemensis* zone, and the *Molopophorus gabbi* zone probably needs revision; but the others appear to be well established and apply equally well to the Oligocene deposits of northwestern Oregon.

ACKNOWLEDGEMENTS

As the result of an intensive study of the stratigraphy of northwest Oregon during 1944-45, a preliminary geologic map has recently been published by the Geological Survey.¹⁵ The present paper describes in greater detail some of the salient stratigraphic features of a part of the area covered by that map. Because

¹¹ C. E. Weaver, "Tertiary Stratigraphy of Western Washington and Northwestern Oregon," *Univ. Washington Pub. in Geol.*, Vol. 4 (1937), p. 104.

¹² *Idem*, pp. 112-113.

¹³ C. E. Weaver, "Paleontology of the Marine Tertiary Formations of Oregon and Washington," *Univ. Washington Pub. in Geol.*, Vol. 5, 1942 (1943). 274 pp., 104 pls.

¹⁴ J. W. Durham, "Megafaunal Zones of the Oligocene of Northwestern Washington," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 27, No. 5 (1944), pp. 101-212.

¹⁵ W. C. Warren, Hans Norbistrath, and R. M. Grivetti, "Geology of Northwestern Oregon West of the Willamette River and North of Latitude 45°15'," *U. S. Geol. Survey Prelim. Map 42*, Oil and Gas Inves. Ser. (1945).

of the nature of the outcrops the study was necessarily based in large part on extensive collections of megafossils, and for that reason a large measure of whatever success was attained by the project belongs to H. E. Vokes for his unstinting labor on the megafossils, as well as for his counsel on stratigraphic problems. A monograph on the megafossils of the Keasey formation is being prepared by Vokes for publication shortly. In the field Weaver's paleontologic monograph was extremely helpful.

A limited amount of work was done with Foraminifera and the writers express their thanks to J. A. Cushman for identifying some of them and to D. C. Duncan for preparing the Foraminifera and studying them.

STRATIGRAPHY

GENERAL STATEMENT

The Coast Range in northwestern Oregon is formed from three distinct groups of rocks. The oldest group is an Eocene sequence of basic lavas with subordinate amounts of tuff and breccia and minor amounts of sedimentary beds. This sequence has recently been described and named the Tillamook volcanic series.¹⁶ It is well exposed in the highest part of the mountain range where it forms a geanticline. Bordering the Tillamook volcanic series on the west, north, and east is a group of marine sedimentary beds of upper Eocene to Miocene age which rest unconformably on the Tillamook volcanic series and dip gently away from the volcanic terrane. Resting unconformably on these sedimentary beds are basaltic lava flows. These flows with their associated intrusive rocks form the third distinct group and are thought to be an extension of the Columbia River basalt.¹⁷ They form resistant cappings of the highlands bordering the Columbia River valley on the north and east sides of the Coast Range. Smaller isolated patches of basalt flows, as well as numerous intrusive bodies which transgress the sedimentary rocks, are found on the north and west sides of the mountains.

The two volcanic series and the intervening sedimentary sequence are all represented in the upper Nehalem River basin. Here the sedimentary sequence is more favorably exposed and contains more megafossils than in other parts of northwestern Oregon.

In general the structure of the Coast Range of northwestern Oregon is an anticline whose crest lies in the central part of the range. The sedimentary rocks on the flanks of the anticline dip at angles up to 15° but dips are locally higher—probably owing to faulting or surficial movement in most such places. The general dip of the sedimentary sequence away from the highlands of resistant volcanic rock is interrupted by northwest-southeast folds which are prominent east of the upper Nehalem River but gradually fade into the regional structure when followed westward to the Tillamook volcanic series. Also, the areal distribution of

¹⁶ W. C. Warren, Hans Norbistrath, and R. M. Grivetti, *op. cit.*

¹⁷ C. E. Weaver, *op. cit.*, "Tertiary Stratigraphy," pp. 171, 184-85.

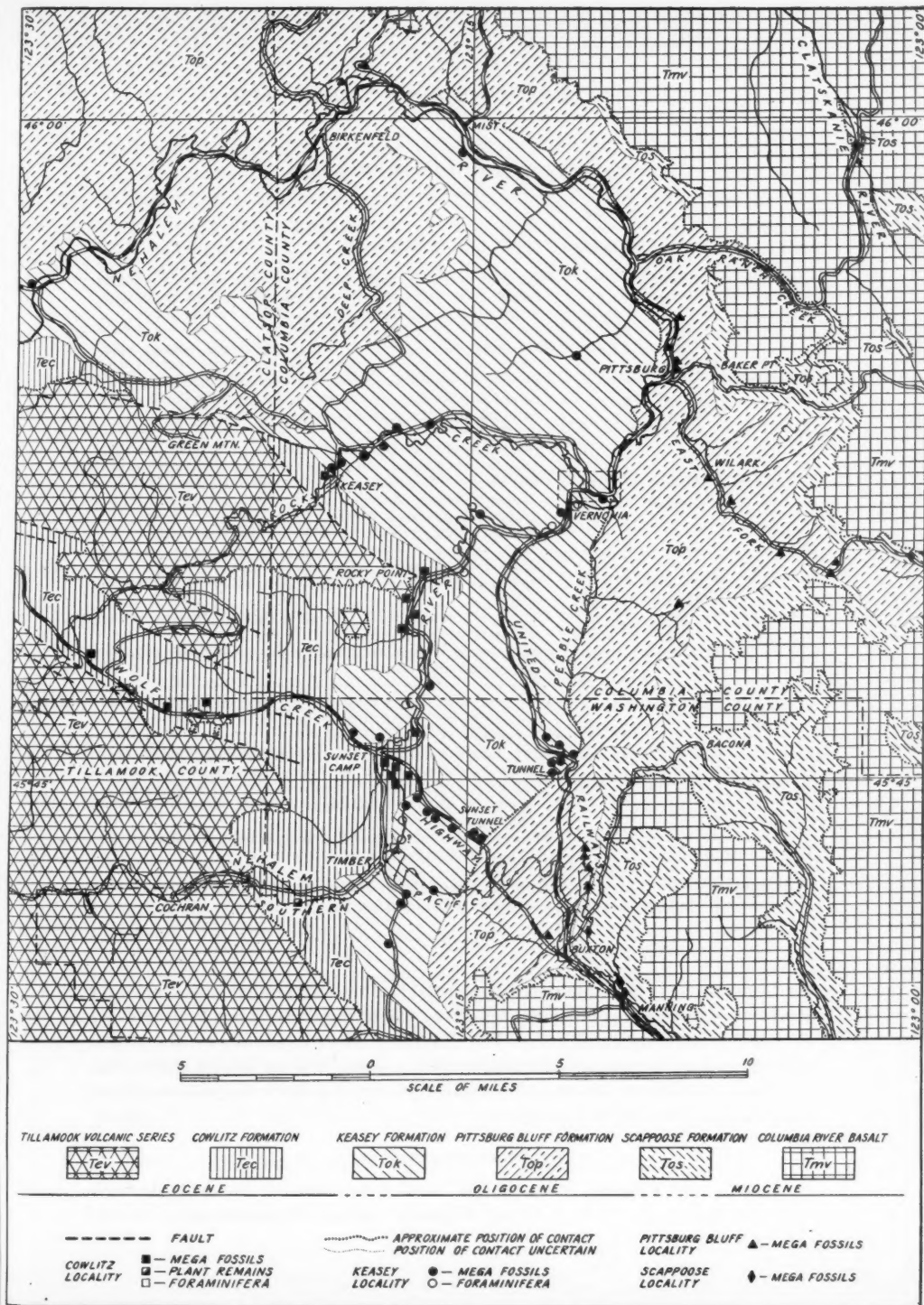


FIG. 2.—Geologic map of upper Nehalem River basin, northwestern Oregon.

TABLE I
FORMATIONS IN UPPER NEHALEM RIVER BASIN

<i>Formation</i>	<i>Age</i>	<i>Thick- ness (in feet)</i>	<i>Description</i>
Columbia River basalt	Middle Miocene	0 to 1,000	Dark gray to black, hard, finely crystalline basalt. Columnar basalt flows in places interbedded with a little pyroclastic material and sediments. Associated intrusive bodies
Scappoose	Lower Miocene or upper Oligocene	1,500	Gray, yellowish-weathering, firm, fossiliferous, sandy, tuffaceous shale and shaly sandstone, commonly spotted with pumiceous material. Loosely consolidated, medium-grained sandstone. In some places strata show pebble bands, cross-bedding, and interbedded carbonaceous material
Pittsburg Bluff	Middle Oligocene	700 to 850	Firm, sparingly fossiliferous, tuffaceous sandstone and shale with beds of fine-grained, white tuff. Stratified, cross-bedded sandstone with pebble bands, and carbonaceous material. Massive, loosely consolidated, brown-weathering medium-grained, micaceous, concretionary sandstone. Gray, fine-grained fossiliferous sandstone with calcareous beds
Keasey	Lower Oligocene and upper Eocene (?)	1,800 to 2,200	Faintly stratified, sparingly fossiliferous, fine-grained, tuffaceous sandstone and tuffaceous shale with bands of pebbles and fine tuff Light gray, unstratified, harsh, tuffaceous siltstone containing scattered well preserved fossils Dark gray, well stratified, fossiliferous claystone and siltstone, with glauconitic layers
Cowlitz	Upper Eocene	950	Dark gray, fossiliferous shales and fine-grained micaceous, shaly sandstone with much interbedded, tuffaceous sandstone and greenish gray, water-laid tuff Gray, massive and stratified, fine- to medium-grained, micaceous sandstone containing much fragmental plant material Dark gray, well stratified, brown-weathering, fossiliferous claystone and siltstone containing a mixture of much white volcanic ash Well indurated, rust-stained, pebble, cobble, and boulder conglomerate, locally fossiliferous
Tillamook volcanic series	Eocene	1,000	Greenish gray, altered and fractured, basic lavas with much interbedded tuff and breccia

the formations is much influenced by normal faults so that inliers of sedimentary strata are preserved as erosional remnants where they have been faulted down between resistant volcanic rocks. The Columbia River basalt lies on the eroded surface of the sedimentary formations with a slight angular unconformity, but has been affected by the same forces which produced gentle northwest-southeast folds in the sedimentary formations.

TILLAMOOK VOLCANIC SERIES

In the upper Nehalem valley the Tillamook volcanic series constitute the highlands southwest of the Wolf Creek Highway and are discontinuously exposed

northward, forming the high country surrounding and including Green Mountain and the headwaters of Rock Creek. More than 1,000 feet of basic lava flows interbedded with much tuff and breccia and very minor amounts of sedimentary beds are present in this area.

Typical exposures can be seen along the Wolf Creek Highway in the eastern parts of Clatsop County and Tillamook County, and along logging roads between the Wolf Creek Highway and Green Mountain. Thin, dark, rust-stained, lava flows, with irregular outlines and tongue-like extensions, are intimately associated with green and gray breccia, which is generally composed of an heterogeneous mixture of varicolored angular pyroclastic fragments. Small shear-planes and irregular joints are common, and in some places grooved and slickensided fault surfaces are well developed. A few flows show poorly developed columnar jointing. Open spaces in the rock are commonly filled or lined with calcite and chalcedonic silica. Alteration of these volcanic rocks commonly gives the exposures a greenish gray color. Locally, chloritization is so advanced that a greenstone has resulted. Relatively fresh samples of the lava exhibit a black to greenish gray, finely crystalline groundmass which commonly appears silky. Megascopic laths and rectangles of plagioclase and rounded crystals of augite are present in some hand samples.

In many exposures basaltic dikes appear that are considerably fresher than the flows and breccias they cut. These dikes probably belong to one of the epochs of more recent volcanism that are known from this general area.

No fossils have been found in the Tillamook volcanic series within the upper Nehalem River basin but a few Eocene marine megafossils have been found in sedimentary beds associated with the volcanic rocks in adjacent areas.¹⁸ The marine megafossils so far identified do not indicate to which part of the Eocene the Tillamook volcanic series belongs, but in one place an *Aralia*¹⁹ of upper Eocene type was found with the marine fossils, and a microfauna from another locality had a number of Cowlitz (upper Eocene) species.²⁰ If the volcanic series is upper Eocene, it must be well down in the upper Eocene, for it is overlain unconformably by marine beds with an unquestionable Cowlitz megafauna and microfauna.

COWLITZ FORMATION

In the upper Nehalem River valley, resting unconformably on lavas and breccias of the Tillamook volcanic series, is a formation composed of conglomerate, shale, sandstone, and some intercalated volcanic materials. These strata, which accumulated under marine and brackish-water conditions, contain a fauna correlative with the type Cowlitz formation in Washington.

¹⁸ W. C. Warren, Hans Norbistrath, and R. M. Grivetti, *op. cit.* (*Prel. Map 42*).

¹⁹ Identified by R. W. Brown.

²⁰ Personal communication from D. C. Duncan.

The type section of the Cowlitz formation according to Weaver²¹ is about 35 miles northeast of the upper Nehalem River basin in Lewis County, Washington, along the banks of Olequah Creek near its junction with the Cowlitz River. The section at that locality includes about 8,000 feet of marine to brackish-water sandstone and shale. Basalt flows are intercalated in its lower part.²² The uppermost 3,745 feet of the section was measured in detail by Weaver²³ and the contained fauna was correlated with the upper Eocene Markley and Tejon (restricted) formations of California. One and one-half miles east of Weaver's type section in a sharp bend of the Cowlitz River there are exposed about 200 feet of richly fossiliferous strata, which Beck²⁴ regards as the type section. Beck would correlate these beds with some part of the upper 900 feet of the type Tejon of California and the middle Coaledo formation of western Oregon.

The strata referred to the Cowlitz formation in the upper Nehalem River basin are exposed in the valleys of small creeks northwest of Green Mountain, in the banks of Rock Creek from Keasey Station upstream to the outcrop of the Tillamook volcanic rocks, in the bed of Nehalem River near Rocky Point, and along the Wolf Creek Highway west of the Nehalem River and adjacent to the Tillamook volcanic series. No complete or well exposed section of the Cowlitz formation is known in this area and the section must be pieced together from many discontinuous and isolated exposures.

On the basis of lithology the Cowlitz formation is tentatively divided into four members: a basal conglomerate, a lower shale member, a sandstone member, and an upper shale member.

The basal conglomerate rests with irregular contact on the underlying lava and breccia of the Tillamook volcanic series. The conglomerate is locally represented by a few scattered waterworn cobbles lying between the older volcanic rock and overlying shale but generally it has a thickness of more than 10 feet and, in a few places, it is more than 200 feet thick.

The general appearance as well as the basal contact of this conglomerate can be observed in road cuts along the Wolf Creek Highway west of Sunset Camp where the highway follows along the contact between the basal conglomerate and the underlying Tillamook volcanic series. Here the conglomerate is composed mainly of hard, well rounded pebbles, cobbles, and boulders of volcanic material interbedded and mixed with dark, coarse, waterlaid tuffaceous sandstone. Occasional boulders up to 3 or 4 feet in diameter can be seen. The conglomerate is well indurated and in places is richly fossiliferous.

²¹ C. E. Weaver (editor), "Correlation of the Marine Cenozoic Formations of Western North America," *Bull. Geol. Soc. America*, Vol. 55 (1944), p. 593.

²² C. E. Weaver, "The Tertiary Formations of Western Washington," *Washington Geol. Survey Bull.* 13 (1916), pp. 92-93, 159-63.

²³ C. E. Weaver, *op. cit.*, "Tertiary stratigraphy," pp. 90-94.

²⁴ R. S. Beck, "Eocene Foraminifera from Cowlitz River, Lewis County, Washington," *Jour. Paleon.*, Vol. 17 (1943), pp. 584-618.

Three miles west of Timber where the basal conglomerate is estimated to be more than 200 feet thick it consists of an heterogeneous assemblage of poorly sorted sand, pebbles, and cobbles with a few boulders as much as 8 feet in diameter near the base of the member. Plant remains are found here. The conglomerate was derived almost entirely from volcanic materials.

At a small quarry on the south side of Rocky Point the basal conglomerate consists of 1 to 2 feet of fossiliferous pebblestone with a calcareous cement and is overlain by several feet of shale.

Fossils found in the basal conglomerate include the following forms.

Glycymeris cf. *eocenica* (Weaver)
Barbatia cowlitzensis (Weaver and Palmer)
Barbatia suzsaloi (Weaver and Palmer)
Ostrea cf. *griesensis* Effinger
Pododesmus n. sp.
Mytilus n. sp. A
Mytilus n. sp. B
Volzella cowlitzensis (Weaver and Palmer)
Pitar cf. *eocenica* (Weaver and Palmer)
Acmaea n. sp. A
Acmaea n. sp. B
Calyptopora diegoana (Conrad)
Terebratalia sp.

The basal conglomerate grades upward rather abruptly into marine shales. In fresh exposures these shales are generally dark, fine-textured and fairly well stratified. Commonly they have a considerable admixture of fine white volcanic ash which gives them a lighter color—particularly in their upper part where the shales become more silty and contain intercalated waterlaid tuffs. Foraminifera and Mollusca are common. This lower shale member is exposed along Wolf Creek Highway near the top of the grade west of Sunset Camp. Generally, exposures of this member are weathered to tan or brown, soft, greasy, crumbly, decomposed shales, which may show faint stratification. The thickness of the member appears to be variable. West of Timber the shales probably have a thickness of several hundred feet but are thinner toward the north where coarser sedimentary beds are predominant.

The lower shale member of the Cowlitz formation is overlain by a sandstone member that is exposed along Rocky Creek above Keasey Station, along the Nehalem River near Rocky Point, and west of Timber. South of Sunset Camp, along the river and adjacent hillside, there is a sandstone that is believed to be the same member occurring at that locality as the result of faulting. The sandstone of this member is gray, fine- to medium-grained, and micaceous and contains much fragmentary plant material. In places the sandstone member is massive but generally stratification is fairly well developed. The sandstone may appear streaky due to the abundant interbedded carbonaceous material. The alternation of fine and coarse sedimentary beds has produced a flaggy well stratified sandstone in places. Cross-bedding and ripple marks are rarely seen. The sandstone locally shows a spottiness due to shale and tuff fragments. Calcareous concretions as much as 3 feet long are not uncommon. This sandstone member rarely

contains shell fragments except near its base where it grades downward into marine fossiliferous siltstone with interbedded tuffs. It is probably between 200 and 300 feet thick south of Sunset Camp.

Overlying the sandstone member is an upper shale member consisting of marine fossiliferous dark gray shale and fine-grained micaceous shaly sandstones, which contain increasing amounts of interbedded tuffaceous sandstone and water-laid tuff in the upper part. These strata represent the uppermost part of the Cowlitz formation. The interbedded tuffs are generally coarse-textured, dark greenish gray, well indurated, and are commonly cemented with calcite which causes them to weather out as resistant bands at various places along the Nehalem River. Occasional pebble bands of tuffaceous material occur. Gastropods are common in these tuffaceous zones although mollusks are scattered throughout this upper member. Where sufficient shaly material is present the beds contain abundant Foraminifera.

The position of the contact between the Cowlitz formation and the overlying Keasey formation along the Wolf Creek Highway east of Sunset Camp is open to question. A pebbly tuffaceous sandstone bed, which disconformably overlies a zone of glauconitic tuffaceous shale, contains Keasey fossils in its upper part and at one horizon in the underlying shale a variant of *Acila decisa* (Conrad) occurs. Inasmuch as *Acila decisa* is not known from beds younger than the Cowlitz formation, the contact would appear to be at the base of the pebbly sandstone. The reasons for doubting this conclusion are that (1) the sandstone is probably the base of the middle Keasey and (2) the *Acila* is not typical *A. decisa* (Conrad). Foraminifera occur in the shale under question and study of these could settle the point.

Continuous exposures of the Cowlitz formation do not occur in the upper Nehalem River valley, and a measurement of the thickness of the formation was not possible. However, a rough estimate indicates a thickness of 950 feet of Cowlitz strata along the Nehalem River between the base of the formation at Rocky Point and the top of the formation north of Sunset Camp.

About 120 species of megafossils have been recognized by Vokes in the Cowlitz formation of the upper Nehalem River valley and adjacent areas. Of these approximately half are identical with or similar to forms found in the type Cowlitz formation; the remainder are new. In addition to the forms listed from the basal conglomerate the following characteristic forms occur at many of the Cowlitz localities in the upper Nehalem River basin.

- Nucula* n. sp.
- Acila decisa* (Conrad)
- Nuculana* cf. *vaderensis* (Dickerson)
- Nuculana cowlitzensis* (Weaver and Palmer)
- Yoldia* aff. *duprei* Weaver and Palmer
- Polinices nuciformis* (Gabb)
- Ficopsis cowlitzensis* (Weaver)
- Siphonalia sopenahensis* (Weaver)
- Conus vaderensis* Weaver and Palmer
- Exilia dickersoni* (Weaver)

Spirotropis n. sp.
Hemipleurotoma pulchra (Dickerson)
Turricula cowlitzensis (Weaver)
Scaphander costatus Gabb
Pilumnoplax hannibalanus Rathbun

Well preserved Foraminifera are fairly abundant in parts of the Cowlitz formation. Preliminary study of these Foraminifera indicates that these beds are close in age to those beds along the Cowlitz River in Washington that Beck²⁶ considers to be type Cowlitz. Certain distinctions can be noted—particularly the absence of *Plectofrondicularia packardi* Cushman and Schenck from the beds on Cowlitz River. The persistence of this form in the beds on the Nehalem River indicates a difference of facies or of age between the beds of the two areas, but it is too early to say which.

KEASEY FORMATION

Along Rock Creek about 0.7 miles below Keasey Station the Cowlitz formation is overlain by possibly 500 feet of dark gray fossiliferous shales which generally show good stratification. These strata, comprising the Keasey shale as originally defined by Schenck,²⁶ are exposed at intervals along Rock Creek and the near-by railroad for about 2 miles downstream from exposures of the Cowlitz formation. The Keasey formation here consists of alternating beds of claystone and siltstone with some glauconitic layers. In places the shale is richly fossiliferous. Although these beds were designated as the type Keasey formation, Schenck, Weaver,²⁷ and the present writers include in the Keasey formation younger beds that crop out farther down Rock Creek, as well as elsewhere in the general area.

The formation consists of a lower dark shale member (type Keasey) whose composition and thickness varies from place to place; a thick, widespread, fairly uniform middle member of massive silty tuffaceous shale with cemented beds; and an upper member of stratified tuffaceous sandy shales.

The best exposures of the lower member of the Keasey formation are at the type locality on Rock Creek. It is also exposed at places along the Nehalem River between Timber and Vernonia but seems to thin southward along the river. Typical exposures of the lower member occur on the Wolf Creek Highway 0.7 mile west of Sunset Camp and on the Nehalem River Highway 0.3 mile northeast of the Columbia County line. East of Sunset Camp along the Wolf Creek Highway the middle and upper members of the Keasey formation are well exposed, but the lower member, as discussed under the description of the Cowlitz formation, is either absent or is represented by 400 feet of glauconitic shales which are tentatively considered to be Cowlitz. Along the Nehalem River between

²⁶ R. S. Beck, *op. cit.* (1943).

²⁶ H. G. Schenck, *op. cit.*, "Marine Oligocene," pp. 457-58.

²⁷ C. E. Weaver, *op. cit.*, "Tertiary Stratigraphy," pp. 105, 171-72.

Rocky Point and Timber the lower member of the Keasey is more glauconitic than at the type locality on Rock Creek.

The middle member of the Keasey formation consists of light gray, unstratified, harsh, tuffaceous siltstone with some hard calcareous beds. It can be seen in good exposures at rare intervals along the Rock Creek road, and in the banks and hillsides along the Nehalem River. The most nearly continuous exposures of the middle member, however, are along the Wolf Creek Highway near Sunset Tunnel where a thickness of approximately 1,700 feet of dark gray, massive, harsh, tuffaceous siltstones with a few layers of ashy tuff and of hard, calcareous siltstone is exposed. Excellently preserved mollusks and foraminifers are scattered through the outcrops. Other good exposures of the middle member occur in high banks along the United Railway in the northern part of Washington County, where fresh exposures of massive tuffaceous siltstones are richly fossiliferous.

The upper member of the Keasey formation is exposed immediately north of the tunnel on the United Railway in northern Washington County, in a railroad cut near the sawmill in Vernonia, and east of Sunset Tunnel on the Wolf Creek Highway. The member consists of from 100 to 200 feet of interbedded claystone, tuffaceous siltstone, and tuff bands. A few diagnostic fossils are present in these exposures.

The only satisfactory measurement of the Keasey formation obtained was along Wolf Creek Highway in the vicinity of Sunset Tunnel where the middle and upper members have a combined thickness of 1,800 feet. Below the middle member there are 400 feet of shales that might, as previously explained, represent the lower member of the Keasey, although at present these beds are regarded as Cowlitz.

West of the upper Nehalem River basin shales of the Keasey formation grade laterally into dark claystones that can not be differentiated lithologically from the claystones of the underlying Cowlitz formation.

The Keasey formation is overlain disconformably by the middle Oligocene Pittsburg Bluff formation.

Some of the Foraminifera of the Keasey formation have been described; and the Keasey formation has been correlated with the Bassendorf shale²⁸ and with the Gaviota formation²⁹ of California. The "*Uvigerina cocoaensis*" zone has been regarded as synchronous with the Keasey formation³⁰ but "*Uvigerina cocoaensis*" Cushman,³¹ which is one of the most abundant forms in the middle and

²⁸ J. A. Cushman and H. G. Schenck, "Two Foraminiferal Faunules from the Oregon Tertiary," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 17 (1928), pp. 305-24.

²⁹ H. G. Schenck and R. M. Kleinpell, "Foraminifera from Gaviota Formation" (abstracts), *Pan-Amer. Geol.*, Vol. 64 (1935), p. 76; *Geol. Soc. America Proc. for 1935* (1936), p. 352.

³⁰ C. E. Weaver (editor), "Correlation of the Marine Cenozoic Formations of Western North America," *Bull. Geol. Soc. America*, Vol. 55 (1944), pp. 569-98.

³¹ In a personal communication from J. A. Cushman, he states that the Keasey form differs from the type *Uvigerina cocoaensis* Cushman from Alabama and is being restudied.

upper members of the Keasey formation, appears to be absent or rare in the lower member, suggesting that the "*Uvigerina cocoaensis*" zone may include only the upper two members of the Keasey. Of 36 previously described species of Foraminifera identified by Cushman from the writers' Cowlitz and Keasey collections,³² 15 species are common to both formations, 12 are restricted to the Cowlitz formation and 9 to the overlying Keasey formation. Inclusion of new species might change the proportions considerably but it is worth noting that many correlations to be found in the literature have been based on smaller degrees of coincidence.

The Keasey formation contains a rich megafauna³³ of which only a few forms have been described. However, a monograph on this fauna is being prepared for publication by H. E. Vokes, and in view of this, the following discussion is purposely kept brief.

The three-fold lithologic division of the Keasey formation appears to be supported by megafaunal differences. *Turricula columbiana* Dall, *Corbis washingtoniana* Clark, and a new species of *Conus* are restricted to the lower member. *Nemocardium weaveri* (Anderson and Martin), *Epitonium condoni* Dall new variety, *Olequahia schencki* Durham, and new species of *Thracia* and *Nekewis* have been found only in the middle member. *Lima oregonensis* Clark, *Porterius gabbi* (Dickerson), *Nemocardium lorenzanum* (Arnold), *Gyrineum jeffersonensis* Durham, and a new species of *Turricula* have been found only in the upper member. The following forms are apparently restricted to the lower and middle members.

Acila nehalemensis Hanna
Pitar clarki (Dickerson)
 "Echinophoria dalli (Dickerson), var." of Durham
Epitonium keaseyense Durham
Epitonium keaseyense schencki Durham
Nekewis aff. washingtoniana (Weaver)

In contrast to the Foraminifera, only one tentative species of mollusk is common to the Keasey and the underlying Cowlitz, whereas 12 of the forms listed above occur in the *Molopophorus stephensoni* or higher zones.

Durham correlated the Keasey shale with the Townsend shale of northwestern Washington and placed both formations in the "*Turricula columbiana* zone."³⁴ Durham based this correlation principally on the occurrence of *Plectofrondicularia packardi* Cushman and Schenck and *Acila nehalemensis* Hanna in both formations; but *P. packardi* is a common foraminifer, in the Cowlitz formation (upper Eocene) as well as in the superjacent Keasey formation, and comparison of Durham's hypotype of *A. nehalemensis* from the Townsend shale with type material from the Keasey formation convinced both B. L. Clark and H. E. Vokes³⁵ that

³² W. C. Warren, Hans Norbistrath, and R. M. Grivetti, *op. cit.* (Prelim. Map 42).

³³ W. C. Warren, Hans Norbistrath, and R. M. Grivetti, *op. cit.* (Prelim. Map 42).

³⁴ J. W. Durham, *op. cit.* (1944), p. 106.

³⁵ Personal communication from H. E. Vokes.

the *Acila* from the Townsend shale is not *A. nehalemensis* but is probably a new species. It is still possible that the Townsend shale is correlative with part of the Keasey formation but it is more probable that the Townsend shale is slightly older than the Keasey formation.

Weaver³⁶ and Effinger³⁷ correlated the Gries Ranch formation with the Keasey formation and placed them both in the lower Oligocene. A typical Gries Ranch fauna has not been recorded from the upper Nehalem River basin but a number of diagnostic Gries Ranch forms are included in the forms listed above from the Keasey formation, suggesting that the two formations may be partly correlative. If so, the faunal differences may be ascribed to ecologic conditions, for the type Gries Ranch fauna is a near-shore facies, whereas the Keasey fauna appears to indicate somewhat deeper water, presumably farther from shore. Until the Foraminifera of the Gries Ranch formation have been studied it would be unwise to correlate definitely that formation with the Keasey, but it does seem likely that at least the upper member of the Keasey formation is of the same age as the Gries Ranch formation.

PITTSBURG BLUFF FORMATION

The richly fossiliferous sandstone forming the bluffs on the Nehalem River Highway near Pittsburg has long been known to paleontologists. This sandstone and other sandy strata exposed at numerous places in the upper Nehalem River basin are referred to as the Pittsburg Bluff formation. In the lower part of the Pittsburg Bluff formation are fine-grained marine sandstones containing numerous fossils in layers along the bedding and in calcareous concretions. These richly fossiliferous sandstones seem to pass upward into coarser massive sandstone which interfingers with cross-bedded, near-shore, marine and brackish-water sandstone. Upward in the formation fossiliferous bands are less common and brackish-water beds with plant remains more common. Toward the top of the formation fossils are few and thick beds of tuffaceous material are prominent. The Pittsburg Bluff formation, although dominantly sandy, shows a wide variation in texture, composition and minor structures. Exposures of sandstone are generally massive but may show stratification, owing to partings, alternating fine and medium-grained layers, or cemented beds. Hand specimens of the sandstone usually show fine to medium grains of quartz, mica, and feldspar with varying amounts of tuffaceous material. The massive sandstones contain occasional calcareous concretions which may be as much as several feet in length (parallel with the bedding) but are usually smaller. Locally, the formation is strongly cross-bedded and has a few bands of pebbles derived from material of volcanic origin. Pieces of lignitized wood and small pieces of vegetal material are commonly seen.

³⁶ C. E. Weaver, *op. cit.*, "Tertiary Stratigraphy," p. 109.

³⁷ W. L. Effinger, "The Gries Ranch Fauna (Oligocene) of Western Washington," *Jour. Paleon.*, Vol. 12 (1938), p. 361.

As would be expected in deposits of this kind, the beds grade laterally from one type to another within short distances. Highway and railroad cuts afford many exposures of the Pittsburg Bluff formation. The fresh rock is gray and firmly compacted. However, owing to deep weathering and the absence of cementing materials, the sandstone in most exposures is loosely consolidated and commonly is colored rusty brown.

The Pittsburg Bluff formation in the upper Nehalem River valley is partly marine and partly brackish-water in origin. Deltaic deposits seem to interfinger with near-shore fossiliferous marine beds in many places. The type exposure of the formation on the Nehalem River Highway near Pittsburg represents marine fossiliferous beds near the base of the formation. On the highway along the east fork of the Nehalem River between Pittsburg and Wilark there are massive, loosely consolidated brown-weathering sandstones with pillow-like limestone concretions and fairly well stratified tuffaceous sandstone and shale containing some fossils. Southeast of Wilark, along the road, higher beds in the formation are well-stratified sandy shales interfingering with gray fossiliferous sandstone; then sandstone with deltaic cross-bedding, a few pebble bands, and much included carbonaceous material. Continuing eastward along the road toward the top of the hill the strata become less sandy, and there are thick beds of white, fine-textured tuff, and a layer of mud-flow containing fragments of volcanic rock. These beds represent the upper tuffaceous part of the Pittsburg Bluff formation.

In the hills southeast of Vernonia the Pittsburg Bluff formation consists of massive, loosely consolidated, brown-weathering sandstone, markedly cross-bedded in places and containing much admixed tuffaceous material. Along an abandoned logging railroad approximately 700 feet of these sandstones are discontinuously exposed. Diller³⁸ describes coal beds on Pebble Creek and the East Fork of the Nehalem River. These coal beds are now difficult to reach and were not seen; but from their location, they appear to be in the Pittsburg Bluff formation. Four miles southeast of Vernonia on a logging road at the headwaters of a tributary of Pebble Creek more than 100 feet of fossiliferous, shaly, fine-grained, marine sandstone is exposed. Thirty-four species of well-preserved Mollusca were collected from this locality, which is as richly fossiliferous as the type locality near Pittsburg.

Along the United Railway between Buxton and the south edge of Columbia County there are discontinuous weathered banks of the Pittsburg Bluff formation. The upper part of the formation, which contains many fine-textured, light-colored tuff beds and a few fossils, is well exposed in the cut-banks of the railroad and in the ravines below the trestles. The thickness of the sandstones lying between the Keasey formation and a cobble conglomerate, believed to be the base of the overlying Scappoose formation, was calculated to be 826 feet; but, because of the presence of a fault and questionable structure in poorly exposed

³⁸ J. S. Diller, *op. cit.* (1896), pp. 463, 491-93.

parts of the section, this figure can only be considered approximate. The upper part of the formation is well exposed along the Wolf Creek Highway east of Sunset Tunnel.

In the hills and along old roads between Green Mountain and Birkenfeld there are exposures of massive, loosely consolidated, medium-grained, brown-weathering, micaceous sandstone with varying amounts of tuffaceous material. At several places along the Nehalem River Highway west of Birkenfeld and in the valley of Deep Creek, well stratified alternating gray shale and fine-grained shaly sandstones contain abundant plant remains. Here and there indeterminate marine mollusks have been found in the well stratified sandstones of the Nehalem River valley west of Birkenfeld but no fossils have been found in the Pittsburg Bluff formation in the hills between Greek Mountain and Birkenfeld. It is likely that these sands accumulated rapidly in a brackish-water environment in which mollusks did not thrive.

Excellent exposures of firmly compacted, sandy shale and sandstone with bands of white, fine-textured tuff occur north of Mist in banks along the highway. These beds are typical of the upper tuffaceous part of the Pittsburg Bluff formation.

The actual contact between the Pittsburg Bluff sandstone and the underlying Keasey formation has not been observed. Differences in trend of the two formations in the Nehalem River valley between Vernonia and Oak Ranch Creek suggest an unconformity with an angular discordance of several, degrees. The Pittsburg Bluff formation is overlain disconformably by the Scappoose formation.

The Pittsburg Bluff formation is characterized by a near-shore megafauna which is rich in the number of individuals of certain species. A representative list of described forms follows.

- Acila shumardi* (Dall)
- Nuculana* aff. *washingtonensis* (Weaver)
- Crenella porterensis* Weaver
- Thracia condoni* Dall
- Taras goodspeedi* Durham
- Macrocallista pittsburgensis* (Dall)
- Pitar dalli* (Weaver)
- Tellina pittsburgensis* Clark
- Tellina* cf. *kamakawensis* Clark
- Solen townsendensis* Clark
- Solena eugenensis* Clark
- Spisula pittsburgensis* Clark
- Spisula packardii* Dickerson
- Spisula veneriformis* Clark
- Panope ramonensis* Clark
- Panope snohomishensis* Clark
- Ervilia oregonensis* Dall
- Neverita nomlandi* (Dickerson)
- Polinices washingtonensis* (Weaver)
- Eosiphonalia oregonensis* (Dall)
- Brucarkia columbiana* (Anderson and Martin)
- Molopophorus gabbi* (Dall)
- Perse pittsburgensis* Durham
- Knefastia washingtonensis* (Weaver)
- Acleon parvum* Dickerson

The only Foraminifera seen in the Pittsburg Bluff formation were a few arenaceous forms.

Durham³⁹ has correlated the Pittsburg Bluff formation and beds at Clatskanie with the middle part of the Quimper sandstone and called this zone the *Molopophorus gabbi* zone. Durham is probably correct in correlating the middle part of the Quimper sandstone with the beds at Clatskanie but these beds are closely related to the Gries Ranch formation and are almost certainly older than the Pittsburg Bluff formation.⁴⁰ Inasmuch as the fauna of the Pittsburg Bluff formation should be considered the type for the *Molopophorus gabbi* zone, a new name is desirable for the zone which includes the middle part of the Quimper sandstone and the beds at Clatskanie. *Molopophorus dalli* Anderson and Martin was described from the beds at Clatskanie and is reported by Durham from the middle part of the Quimper sandstone, so that this zone might appropriately be called the *Molopophorus dalli* zone. This form has not been found in the Pittsburg Bluff formation.

The relation of the restricted *Molopophorus gabbi* zone to the *Turritella olympicensis* zone is uncertain.

SCAPPOOSE FORMATION

Overlying the Pittsburg Bluff formation in the upper Nehalem River valley is a formation composed of tuffaceous sandstones and shales, which are capped by Columbia River basalt. These sedimentary beds are lithologically similar to the upper tuffaceous part of the Pittsburg Bluff formation on which they rest, but the fauna which they contain is distinct from the fauna of the Pittsburg Bluff formation. Extensive erosion prior to the extrusion of the Columbia River basalt has removed part of this formation so that its thickness and distribution are erratic. The name Scappoose formation is proposed for these strata. They are best exposed east of the upper Nehalem River basin in the hills along the west side of the Columbia River, and typical exposures of this formation, as well as the underlying Pittsburg Bluff formation, occur in the valley of the South Fork of Scappoose Creek and along Rocky Point road a few miles east and southeast of the town of Scappoose on the Columbia River Highway.

The lithologic similarity of the Scappoose formation and the upper part of the Pittsburg Bluff formation makes it difficult to differentiate these units without the use of fossils. Although the Scappoose formation is generally fossiliferous, deep weathering of the easily decomposed tuffaceous material has so affected the rock that fossils are mainly fragile casts. For this reason the distribution of the Scappoose formation in the mapped area is incompletely known.

Weathering of the tuffaceous sediments along steep hillsides has facilitated gravitational action so that varying amounts of the overlying lava have worked

³⁹ J. W. Durham, *op. cit.* (1944), p. 112.

⁴⁰ W. C. Warren, Hans Norbistrath, and R. M. Grivetti, *op. cit.* (*Prelim. Map 42*); faunal list for loc. M-11.

down to lower levels. Ultimate decomposition of this material scattered superficially over the Scappoose beds commonly gives a red discoloration to exposures. Normally the rock weathers from firm, light-colored, tuffaceous shales and sandstones to soft, yellowish, greasy, sandy clays and clayey sands.

In the upper Nehalem River basin the Scappoose formation is exposed as inliers along the headwaters of Clatskanie River. In the hills southeast of Baker Point and along the highway east of the headwaters of the East Fork of Nehalem River there are weathered, yellowish, unstratified and poorly stratified shales and sandstones with large amounts of decomposed tuffaceous material. These beds contain fossils in some places. Typical exposures of yellowish-weathering tuffaceous sandstone and shale can be seen in cuts along the road between Buxton and Bacona, and from Bacona southeasterly along a mountain road. The best exposures of the Scappoose formation in the area covered in this report are along the United Railway and adjacent roads from Manning northwesterly to about $1\frac{1}{2}$ miles north of Buxton where the underlying beds of the Pittsburg Bluff formation appear. A conglomerate composed of cobbles and boulders of basic lava is believed to be the base of the formation here. The lower part of the Scappoose formation is fairly well exposed in high banks along the railroad north and east of Buxton where it consists of firm, fine and medium-grained, tuffaceous, shaly sandstone and tuffaceous shale commonly spotted with fragments of pumiceous material. Bands of waterworn pebbles, cross-bedding, leaf imprints, carbonized wood fragments, and a few fossils can be seen in the rock. The middle part of the formation is mostly concealed but several exposures of loosely compacted, medium-grained, massive, micaceous sandstone indicate its composition. The upper part of the Scappoose formation is exposed along roads adjacent to the United Railway for a mile north of Manning. It is less sandy than the underlying part of the formation and consists of gray, firm, somewhat spotted, poorly stratified, fine, sandy, tuffaceous shale with a few fossiliferous zones. Above these beds are the Columbia River basalt. The measured thickness of the Scappoose formation in the Buxton-Manning area is approximately 1,500 feet, but this figure is subject to considerable error because of the horizontal distance involved, long concealed intervals, and possible faulting.

North and east of Vernonia the formation is only a few hundred feet thick or absent altogether where erosion was particularly vigorous before the overlying lavas were extruded. The Scappoose formation seems to rest disconformably on the underlying Pittsburg Bluff formation and is separated from it by a conglomerate of variable thickness.

The Scappoose formation in the upper Nehalem River basin and near-by areas commonly contains the following forms.

- Acila muta* (Clark)
- Acila* aff. *gettysburgensis* (Reagan)
- Nuculana* sp.
- Yoldia chehalisensis* (Arnold)
- Yoldia* aff. *oregona* (Shumard)
- Anadara* cf. *montereyana* (Osmont)

Mytilus cf. mathewsoni Gabb
Thracia aff. trapezoides Conrad
Venericardia cf. hannaï Tegland
Taras parilis (Conrad)
Clinocardium scappooseensis (Clark)
Nemocardium lorenzanum (Arnold)
Macrocallista weaveri Clark
Pitar arnoldi etheringtoni (Tegland)
Tellina oregonensis Conrad
Macoma twinensis Clark
Spisula albaria scappooseensis Clark
Spisula ramonensis attenuata Clark
Panope ramonensis Clark
Bruclarkia acuminata (Anderson and Martin)
Perse aff. lincolniensis (Weaver)

Clark correlated the fauna of the beds herein described as the Scappoose formation with the fauna of the Sooke formation,⁴¹ which Durham⁴² places in the *Echinophoria apta* zone. Further study of the Scappoose fauna supports Clark's correlation.

COLUMBIA RIVER BASALT

The hilly upland bordering the upper Nehalem River valley on the east and north is capped by basalt flows. These basalts appear to be traceable eastward through the gorge of the Columbia River and are widespread over parts of Washington, Oregon, and Idaho where they have been called the Columbia River basalt. The basalts capping the Tertiary sedimentary beds of the upper Nehalem River basin are probably near the westernmost margin of the widespread Columbia River basalt. Excavations along highways and logging roads in the hills northeast and southeast of Vernonia have exposed the Columbia River basalt in a few places.

The Columbia River basalt is composed of flows of basaltic lava of varying thickness which generally rest directly one on the other but may be separated by beds of pyroclastic material or waterlaid sediments. The fresh basalt is a hard, dark gray or black, finely crystalline rock. Individual flows are commonly differentiated by well developed columns perpendicular to the surface of the flows and by vesicular upper surfaces. Most exposures of the Columbia River basalt in the upper Nehalem River basin are weathered to shades of brown or red; and deep red zones of bauxitic laterite have formed on upland areas that are remnants apparently of an old weathered surface which developed on top of the sequence of Columbia River basalt. The contact between the underlying sedimentary beds and the basalts is generally obscured by soil creep and landslides which are common along the steep hillsides at the margins of the lavas. Misleading relationships are suggested in places by intrusive basalt bodies transgressing the sedimentary beds. These irregular dike-like masses were presumably feeders to the basalt flows. They are characterized by small well developed columns which form fan-

⁴¹ B. L. Clark, and Ralph Arnold, "Fauna of the Sooke Formation, Vancouver Island," *Univ. California Pub., Bull. Dept. Geol. Sci.*, Vol. 14 (1923), p. 125.

⁴² J. W. Durham, *op. cit.* (1944), p. 113.

like or radiating patterns in contrast to the larger, more regular and parallel columns characteristic of the flows. A conglomerate, which is believed to be the base of the Columbia River basalt in some places, is exposed near Baker Point and at one place on the road between Buxton and Bacona. This conglomerate is composed of hard, well rounded pebbles and cobbles of basalt with a quartzose sand matrix.

The Columbia River basalt rests unconformably on a maturely eroded surface of Tertiary sedimentary beds. Between Baker Point and Oak Ranch Creek, and in the hills in the vicinity of Manning the surface below the basalt has a relief of several hundred feet. As the Columbia River basalt has long been subject to erosion, its original upper limit is not known. Within the confines of the upper Nehalem River basin it is at least 500 feet thick, but a few miles south of this area, it is known to be at least 1,000 feet thick.

The only evidence afforded on the age of the Columbia River basalt in the upper Nehalem River basin is (1) that it rests on the strongly eroded surface of the Scappoose formation (upper Oligocene or lower Miocene) and (2) the extrusion of the basalt was followed by a long period of erosion. Based on his regional studies of these volcanic rocks, Weaver⁴³ states that:

These lavas on the Washington side contain intercalations of marine sandstone with fossils of the Astoria formation and on this evidence, the lavas and intercalated sediments, east, northeast, and southeast of Pittsburg are regarded as of middle Miocene age.

In the vicinity of Portland, Oregon, the Columbia River basalt is overlain unconformably by the Troutdale formation, which contains a flora regarded by R. W. Chaney⁴⁴ as early Pliocene.

GEOLOGIC HISTORY

The earliest record of geologic events in the upper Nehalem River basin is in the rocks of the Tillamook volcanic series. The basic lavas and pyroclastic materials of that series probably accumulated from intermittent volcanic activity and piled up until the hilly surface was somewhat above sea-level. Depression of this land surface in upper Eocene time allowed the sea to encroach rapidly to form an archipelago. Stream erosion and wave action combined to form the conglomerate member at the base of the Cowlitz formation from the debris of the Tillamook volcanic series. Continued subsidence of the land resulted in a marine embayment of moderate to shallow depths which extended across northwestern Oregon and thence southward along the present Willamette Valley and northward into Washington. The central part of the present Coast Range may have remained above water.

Streams flowing into this embayment in Cowlitz time from the east brought

⁴³ C. E. Weaver, "Tertiary Stratigraphy of Western Washington and Northwestern Oregon," *Univ. Washington Pub. Geol.*, Vol. 4 (1937), p. 171.

⁴⁴ Personal communication from E. M. Baldwin, Oregon State Department of Geology and Mineral Industries, Portland, Oregon.

sands, silts, and clays derived from the erosion of varied terranes. Volcanic ash and lapilli were contributed by intermittent volcanic activity in adjacent areas and local lava flows occurred within the embayment. Although the tuffaceous shales of the Cowlitz formation contain fossils indicative of shallow to moderately deep marine waters, the sandstone member contains much carbonaceous material and the general absence of marine fossils suggests that it may have been deposited in brackish water. At the end of Cowlitz time deposition was slow and ceased with the withdrawal of the Cowlitz sea.

Another influx of oceanic waters at the beginning of Keasey time brought with it a group of marine organisms generically similar to those that lived in the Cowlitz seas but with almost no species of megafossils in common. Although the megafauna of the Cowlitz formation is markedly different from the megafauna of the Keasey formation, the only evidence of a physical break between the two formations is a zone of pebbly, tuffaceous sandstone and shale at the base of the Keasey formation. The microfaunas of the two formations are distinctive but the difference is not nearly so great as between the megafaunas. Woodring⁴⁵ has suggested that the marked difference between the megafaunas of the upper and lower parts of the Gaviota formation in California may be due to an influx of Asiatic forms in the upper Gaviota. This may be the explanation of the difference between the megafaunas of the Cowlitz and Keasey formations. If this is the right explanation, the change in megafaunas suggests that the upper part of the Cowlitz formation is equivalent to the lower part of the Gaviota formation and that the Keasey formation is at least partly equivalent to the upper part of the Gaviota formation.

The first sediments deposited in the Keasey sea were pebbly tuffaceous sands and silts. Tuffaceous silts continued to accumulate during the early part of Keasey time but numerous glauconitic layers suggest that the sedimentation was intermittent. At least one basalt flow was spread out on the sea floor. During the middle part of Keasey time tuffaceous silts continued to accumulate but at a more uniform rate. During the latter part of Keasey time tuff beds and tuffaceous pebbly sandstones interbedded with siltstones indicate more erratic conditions, heralding withdrawal of the Keasey sea. The sediments of the Keasey formation were derived almost entirely from the erosion of volcanic terrane and contributions from contemporaneous volcanism. Both types of volcanic material came from the east.

The close of Keasey time was marked by regional elevation of northwestern Oregon but the newly uplifted land probably did not stand very high, for the discordance between the Keasey formation and the overlying Pittsburg Bluff formation is slight and the erosion surface on which the Pittsburg Bluff formation was deposited had but little relief.

⁴⁵ W. P. Woodring, "Age of the Orbitoid-Bearing Eocene Limestone and *Turritella variata* Zone of the Western Santa Ynez Range, California," *San Diego Soc. Nat. History Trans.*, Vol. 6 (1931), pp. 160-61.

In Pittsburg Bluff time, when subsidence of land areas in northwestern Oregon again took place, a sedimentary record different in character from those of the preceding Cowlitz and Keasey formations was begun. It is likely that differential crustal warping took place in early middle Oligocene time so that some areas were depressed below sea-level and other adjacent areas remained stable or were elevated. With the ingress of marine waters over parts of northwestern Oregon, marine life, different from that of former times, inhabited both the new sea bottom and the shallow water. This new fauna was partly due to evolutionary development of forms present in the Keasey formation but even more was due to an influx of new forms into a different environment. The Pittsburg Bluff fauna contains species of shallow-water, burrowing mollusks which live on sand and mud bottoms.

The sediments of the Pittsburg Bluff formation were deposited in a relatively shallow seaway bounded by shifting deltas and brackish-water embayments. Land areas to the east furnished the sand of which the bulk of the lower half of the Pittsburg Bluff formation is composed. During later Pittsburg Bluff time volcanism in near-by land areas became increasingly active. In the upper part of the formation pyroclastic material is so abundant that sandy, tuffaceous shales alternate with thick beds of fine-textured, light-colored tuffs. The rapid filling of shallow seaways in late Pittsburg Bluff time was probably accompanied by general elevation of the land which eventually emptied the Pittsburg Bluff embayment and initiated a cycle of erosion.

During late Oligocene time subsidence of land areas in different parts of the Pacific Northwest again took place and possibly continued into the lower Miocene. In the upper Nehalem River area a subsiding trough which may or may not have been connected with similar seaways in other parts of Oregon and Washington made possible the accumulation of perhaps 1,500 feet of Scappoose sediments consisting of marine tuffaceous shales and sandstones. The mollusks that lived in the Scappoose seaway were similar in facies to those of the Pittsburg Bluff formation but evolutionary changes differentiate the two faunas. The sandstone of the Scappoose formation may have been derived in part from erosion of the Pittsburg Bluff formation and in part from erosion of terranes farther east. The tuffaceous constituents were probably furnished by contemporaneous volcanism as well as the erosion of older volcanic formations at the east.

The interval of Scappoose deposition was brought to a close by marked regional elevation of land in all parts of western Oregon and Washington sometime during the early Miocene. Oceanic waters retreated far to the west. The elevated land areas were stable during a part of early Miocene time so that the attendant long period of erosion lowered land levels and sculptured the surface into hills and valleys. When the land again subsided an irregular advancement of marine waters in middle Miocene time covered that part of northwestern Oregon lying immediately northwest of the upper Nehalem River of present time. It is likely that this regional downwarp included the area now occupied by the upper Ne-

halem River but that the land here was not depressed below sea-level. Sometime during middle Miocene time volcanic activity began in the upper Nehalem River basin and basalt flows piled up until a thickness of at least 1,000 feet of lavas had accumulated over the deeper valleys. The number of flows decreases rapidly westward from the upper Nehalem River valley and it is not at all certain that these Miocene lavas ever covered the southwestern corner of the upper Nehalem River area. Eastward these Miocene lavas are apparently traceable into the classic area of Columbia River lavas of eastern Washington and Oregon and southwestern Idaho.

Subsequent to the close of the Miocene volcanism the upper Nehalem River basin has been elevated, warped into gentle northwest-southeast folds, and subjected to long periods of erosion separable into several epochs of stream adjustments.

Pliocene volcanism and sedimentation in nearby areas have left no record in the upper Nehalem River valley.

FOSSIL PLANTS AND JURASSIC-CRETACEOUS BOUNDARY IN MONTANA AND ALBERTA¹

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ABSTRACT

Fossil plants support the hypothesis that an unconformity in the basal part of the Kootenai formation in Montana as it has been generally defined in the literature, and at the base of the lower Blairmore formation in Canada, marks the Jurassic-Cretaceous boundary. Comparison of the floras on both sides of the unconformity heightens the probability that the part of the Kootenai below the unconformity is to be included in the Morrison formation, which then is most likely equivalent in whole or large part to the Kootenay of Canada; and that the upper part of the Kootenai of the United States corresponds in large part with the lower Blairmore of Canada. The flora of the upper part of the Kootenai and of the lower Blairmore is an accepted Lower Cretaceous flora that contains several characteristic species not yet reported from any strata below the unconformity, or indeed, from any Jurassic strata.

JURASSIC-CRETACEOUS BOUNDARY

During the field season of 1944 the writer spent 4 weeks collecting fossil plants from the lithologic units now known as Morrison and Kootenai in the United States, hoping that he might find floral evidence for clearly differentiating these formations and thus help to solve the Jurassic-Cretaceous boundary problem. Simultaneously this problem was attacked from stratigraphic and paleozoölogic angles by J. B. Reeside, Jr., Ralph W. Imlay, T. A. Hendricks, J. D. Love, C. E. Erdmann, and their assistants, of the United States Geological Survey, and by several geologists representing oil companies. To these colleagues and particularly to W. A. Cobban, of the Carter Oil Company, and to Oscar O. Mueller and Judge Leonard DeKalb, of Lewistown, Montana, the writer is grateful for much valuable advice and assistance.

The stratigraphic and paleozoölogic studies have resulted in the publication of several papers (Cobban, 1945; Cobban, Imlay, Reeside, 1945; Imlay, 1945) giving significant data toward the solution of the problem. Specifically, Cobban's studies (1945, pp. 1270, 1281) demonstrate the presence of an erosion interval, not hitherto suspected, that marks an unconformity between the Morrison formation or older Jurassic formations and a basal sandstone or conglomerate of the Kootenai formation in the vicinity of Cut Bank, Montana. Extended south-eastward toward Great Falls and Lewistown, this horizon corresponds with a level at or just above the coal bed that occurs in the basal part of the unit now known as Kootenai in Montana (originally named Yellowstone formation and then Dakota sandstone by Weed). This coal is 75 feet, more or less, above the stratum that Fisher (1909, p. 50) and Calvert (1909, pp. 25-27) considered to be the top of the Morrison, the 75-foot sequence consisting of unfossiliferous, soft, greenish or reddish sandy shale.

¹ Manuscript received, November 10, 1945. Published by permission of the director of the Geological Survey, United States Department of the Interior.

² Geologist, Geological Survey.

In Canada a comparable condition is present. The base of the lower Blairmore is marked by a persistent conglomerate 15 to 25 feet thick (Rose, 1917, p. 110; McLearn, 1945, p. 2), which rests on the eroded surface of the coal-bearing Kootenay (McLearn and Hume, 1927, p. 241). Moreover, using the unconformity as a reference line, and placing the United States and Canadian sections side by side, one can see a striking lithologic similarity, unit for unit above and below the unconformity. This similarity has been noted before, and cross-correlation has been hinted by McLearn and Hume (1927, p. 241): "The Kootenai [as defined by Fisher and Calvert] of Montana appears to be equal to the Kootenay of southwestern Alberta plus a part of the Blairmore formation." McLearn, Bell (1944, p. 7), and others, however, continue to assign the Kootenay to the Lower Cretaceous.

Does Cobban's unconformity represent a significant stratigraphic break—the Jurassic-Cretaceous boundary? Does the paleontologic evidence lend credence to this hypothesis?

ANIMAL FOSSILS

Characteristic vertebrate remains are abundant in the Morrison and include fishes, reptiles, and mammals. The Kootenai of Montana has yielded fish and reptilian remains. By contrast neither the Kootenay nor lower Blairmore of Canada has yielded any reported vertebrates, so that no comparison of these units can be made on this basis. The Morrison and Kootenai of the United States contain distinctive ostracodes, according to Peck (1941, p. 287) and others. Insect remains, such as beetle elytra, which the writer collected from the carbonaceous shales associated with the coal, have not yet been identified. No invertebrates have been reported from the Kootenay of Canada, so that comparison with the Morrison on that basis is precluded. The lower Blairmore of Canada, however, contains four species of fresh-water mollusks found also in the Kootenai of Montana: *Unio* [*Elliptio*] *douglasi* Stanton, *Unio* [*Elliptio*] *hamili* McLearn, *Unio* [*Quadrula*] *natosini* McLearn, and *Sphaerium* *onestae* (McLearn). This is part of the reason for the following statement by McLearn (1929, p. 104):

Therefore, the lower 1,380 feet or so of the Blairmore formation of the Blairmore and South Fork areas are to be correlated with a part of the Kootenai of Montana. The American Kootenai of Montana is probably equal to the Canadian Kootenay plus at least part of the Blairmore formation of the Blairmore and South Fork areas.

PLANT FOSSILS

The writer's visit to the Morrison-Kootenai terrane of Montana resulted in the relocation of the old and the discovery of new fossil plant localities. Unfortunately, a box containing some of the most significant material was lost or destroyed while in transit from Lewistown, Montana, to Washington, D. C. The remaining fossils, nevertheless, substantially supplement the previous collections stored in the United States National Museum, and these now permit a clearer

analysis of the floras involved in the Jurassic-Cretaceous boundary question.

Until these collections arrived there were few authentic Morrison plants at hand for study and comparison. The cycadeoid trunks, said by Marsh to have come from 40 feet above the *Baptanodon* beds in the Morrison of the Freezeout Hills, Wyoming, appear to be from the Lower Cretaceous instead. A small collection, made in 1944, by W. L. Stokes, of the United States Geological Survey, from a lower sandstone of the Morrison 15 miles southeast of Thompsons, Utah, contains stout, thorny stems that simulate *Withamia*, *Sewardia*, and *Cycadorachis* from foreign Jurassic localities.

Lest anyone should still entertain the misapprehension that dicotyledonous plants were found in the Morrison of Colorado, a few words of explanation may clarify matters. The title, "A Dicotyledonous Flora in the Type Section of the Morrison Formation," of a paper by Knowlton (1920), reflects the divergence of opinion at that time concerning the Jurassic-Cretaceous boundary at what was considered to be the type locality of the Morrison, near Morrison, Colorado. G. H. Eldridge named and described the Morrison formation in 1896, setting its upper limit at the base of a conglomerate which he assigned to the Dakota group. In 1916 W. T. Lee collected some dicotyledonous plants from No. 4 of his column (1920, p. 184) at the type locality of the Morrison, and assuming that these came from within the limits set by Eldridge for the Morrison, sent them to F. H. Knowlton for identification and description. Knowlton emphatically stated that the plants are definitely Upper Cretaceous species. Berry (1933) rediscussed these plants and concluded that they may indicate either late Lower Cretaceous or early Upper Cretaceous age. Therefore, the strata yielding these plants can not belong to the Jurassic Morrison. Lee (1927, Pl. 1) designated the Morrison as Lower Cretaceous (?) and indicated that a widespread unconformity is present at its top and that conglomerate and sandstone rest on its eroded surface. Thus, Lee's conglomerate and Eldridge's conglomerate are apparently one and the same. The plants came from a sandy shale just above this conglomerate, which, together with the shale, constitutes what Lee identified as the Purgatoire formation of Lower Cretaceous age. To settle the controversy concerning the limits of the Morrison, Waldschmidt and LeRoy (1944, p. 1100) have suggested a new type section located along the West Alameda Parkway road cut, 2 miles north of Morrison. They accept the base of Eldridge's and Lee's conglomerate as the top of the Morrison formation.

In Montana the Morrison (called Cascade formation by Weed), as defined by Fisher and Calvert, is practically barren of plant fossils throughout most of its sequence. Among the lower and middle strata, however, are beds of platy, marly limestone that contain abundant oögonia of the alga, *Chara*. Weathered surfaces of some slabs are peppered gray with these spiral-ridged minute objects that stand out prominently.

However, if the Morrison be enlarged to include the 75 feet, more or less, of basal beds hitherto referred to the Kootenai, that is, all the greenish to reddish

shales and the coal, with its associated dark shales, up to the unconformity of Cobban, then a small florule of ferns, cycads, and conifers becomes available for comparison with the flora found in the overlying strata. These plants occur chiefly in the floor and roof shales of the coal, or their lateral equivalents, cropping out in the vicinity of Belt and Armington on Belt Creek, 20 miles southeast of Great Falls, Montana, and on Geyser Creek, 6 miles southwest of Geyser, Montana. The lowest leaf horizon is a sandy shale 45 feet below the coal on Hazlett Creek, southwest of Stanford, Montana.

In Canada the Kootenay, which for the sake of discussion, is here assumed as the equivalent, in part at least, of the enlarged Montana Morrison, was named and described by G. M. Dawson and Sir William Dawson (1886, p. 2). Fossil plants were collected at five principal localities said to occur within the Kootenay: Anthracite, Canmore, Coal Creek, Crowsnest Pass, and Martin Creek—all in the vicinity of Bow River in southwestern Alberta. Internal evidence leads one to suspect that the floras from these several localities differ considerably in age. Whether all these localities belong in a mappable Canadian Kootenay will probably be determined presently by the field work and researches of Walter A. Bell, of the Canada Geological Survey; but, until the status of these localities is definitely determined, the use of the fossil plants from them for correlation purposes will be fraught with some uncertainty. Furthermore, Dawson's illustrations of some of this material indicate that better examples should be sought, a statement that applies as well to much of the illustrated material from the Kootenai of Montana.

The total published flora from the enlarged Montana Morrison, together with identical species from the Canadian Kootenay, comprises the following items. The names used are generally those of the original citations; but it should be understood that many of these names may have to be changed after the flora has been thoroughly restudied. Omitted from the list are all undescribed new species, because the purpose of this paper is obviously not taxonomic.

FLORA OF ENLARGED MORRISON FORMATION

Charophytes.—The oögonia of *Chara* and related genera, described from the Morrison, come from thin limestones about 100 feet below the unconformity. Those from the Kootenai are from limestones 100 feet or more above the unconformity. According to Peck (1941, p. 287) the assemblages are distinctive and can be readily separated. Unfortunately, collections have not yet been taken from the immediate vicinity of the unconformity, so that a more conclusive test of the stratigraphic value of these microfossils remains to be made.

Acrostichopteris fimbriata Knowlton (1907, p. 110, Pl. 11, Figs. 3, 3a).—Superficially this fern resembles *A. parvifolia* Fontaine and other species from the Lower Cretaceous Potomac group of the Atlantic Coastal Plain and *A. ruffordia* Seward from the Wealden of England, the resemblance being perhaps closest to the latter. Thus, not having Seward's specimen at hand, and the venation not

being clear in his illustration, the writer can not exclude the possibility of close relationship or perhaps identity with the Morrison specimen. The forked venation is more open, and the outline of the pinnules rounder than in any comparable American Lower Cretaceous species.

Adiantum montanense Knowlton (1907, p. 112, Pl. 12, Figs. 1, 2).—This fern has no comparable Jurassic or Lower Cretaceous species, except that known as *A. formosum* Heer [*Ginkgoites* sp. Seward] from the Kome beds at Avkrusak, Greenland. The latter species, however, has larger pinnules with coarser venation and may well be regarded as a different species, perhaps in a different genus. Its reference to *Ginkgoites* by Seward needs re-examination, but *Adiantum montanense* is definitely not ginkgoaceous, for the pinnules, which are nearly sessile, are borne on what evidently were thin, flexible stipes. It is unlikely, except under very unusual circumstances, that ginkgoaceous twigs would retain their leaves while getting into the fossil record.

Cladophlebis constricta Fontaine (1905, p. 297, Pl. 71, Fig. 26).—This specimen, *C. fisheri* Knowlton (1907, p. 109, Pl. 11, Fig. 2), and *Dryopteris? kootaniensis* Knowlton (1907, p. 111, Pl. 11, Figs. 4, 4a), seem to constitute a closely related group, perhaps a single species, which in turn may be identical with *Cladophlebis heterophylla* Fontaine.

Cladophlebis falcata montanensis Fontaine (1905, p. 291, Pl. 71, Figs. 14-20).—This species probably includes part of *Dicksonia pachyphylla* Fontaine (1905, p. 288, Pl. 71, Figs. 5, 6) and *Asplenium martinianum* Dawson (1886, p. 5, Pl. 1, Fig. 1), all from the Morrison and Kootenay. Probably closely related to these is *Asplenium distans* Heer (Dawson, 1886, p. 5, Pl. 3, Fig. 7). Specimens closely resembling these, if not identical with them, have, however, been collected by W. A. Cobban from the Kootenai near Great Falls, Montana.

Cladophlebis heterophylla Fontaine (1892, p. 493, Pl. 84, Fig. 2; 1905, p. 294, Pl. 71, Figs. 21-25).—The type specimen is poorly preserved, but displays almost entire pinnules near the base, whereas the other specimens have pinnules that are neatly cut to the rachis into two series of triangular to rounded divisions. Whether this feature, together with the generally smaller and more delicate habit, constitutes specific difference, it is difficult to decide without more material. However, the type is said to have been found about 200 feet above the unconformity, and the remainder in the shales associated with the coal.

Coniopteris pachyphylla (Fontaine) Berry (1929, p. 42, Pl. 7, Figs. 1-4).—This species probably includes at least part of *Dicksonia pachyphylla* Fontaine (1905, p. 288, Pl. 71, Figs. 7-11) and part of *Dicksonia montanensis* Fontaine (1905, p. 286, Pl. 71, Figs. 1-4). It is a fruiting fern with large sori at the ends of stubby subdivisions of the pinnules. Berry reported it from both the Kootenay and lower Blairmore of Canada, and Fontaine hesitantly identified it from the Shasta series of California.

Oleandra graminaefolia Knowlton (1907, p. 113, Pl. 11, Figs. 5, 5a, 6, 6a); Berry (1929, p. 38, Pl. 5, Figs. 5, 6).—Irregular transverse wrinkling on these

thick, long, narrow leaves was mistaken by Knowlton and copied by Berry as forked venation, and in consequence, the specimens were identified as a species of fern,—possibly an epiphytic fern. In exactly the right light and magnification, however, fine striations suggesting stomatiferous lines can be seen dimly paralleling the thick midvein, thus suggesting that these leaves may be needles of a conifer. As no complete specimens have been found, comparison with outside material is not yet feasible. The specimens identified as *Pinus nordenskioldi* Heer by Dawson (1893, p. 88, Fig. 9) from Anthracite, Alberta, appear to belong with this species, which seems to be confined to the coal horizon.

Thyrsopteris elliptica Fontaine (1905, p. 290, Pl. 71, Figs. 12, 13 only).—This delicate fern seems to have no outside distribution but has larger, coarser relatives identified as *Onychiopsis* in the Lower Cretaceous of the Atlantic Coastal Plain.

Equisetum lyelli Mantell (Fontaine, 1905, p. 301, Pl. 72, Figs. 12–14; Dawson, 1893, p. 83, Fig. 1).—Not much can be said about this and the following species.

Equisetum phillipsi (Dunker) Brongniart (Fontaine, 1905, p. 298, Pl. 72, Figs. 1–11).

Lycopodites? montanensis Fontaine (1905, p. 302, Pl. 72, Figs. 15, 16).—This poorly preserved specimen, doubtfully identified, seems unimportant in the present connection.

Cycadeospermum montanense Fontaine (1905, p. 310, Pl. 73, Fig. 7).—This object, whatever it is, at this time seems to lack comparative significance.

Nageiopsis montanensis Fontaine (1905, p. 312, Pl. 73, Fig. 10).—This leaf with parallel veins may represent *Podozamites*, as Berry (1929, p. 50) surmised when reporting similar fragments from the Canadian Kootenay. Not enough material is known to make adequate comparisons with specimens from other horizons.

Nilssonsonia schaumbergensis (Dunker) Nathorst (Fontaine, 1905, p. 303, Pl. 72, Figs. 17–21; Berry, 1929, p. 47, Pl. 7, Fig. 5).—Questions might be raised here regarding this identification and the separation of this species from the Jurassic *Nilssonsonia compta* (Phillips) Göppert, *N. parvula* (Heer) Fontaine, and *N. nipponensis* Yokoyama. As illustrated by Dunker, the outline and habit of *N. schaumbergensis*, which is from the European Wealden, simulate those of the foregoing species, but its venation, if correctly depicted, is coarser, the veins being fewer and more widely spaced. No comparable form has been found in either the Canadian Kootenay or lower Blairmore, but a species called *N. nigracollensis* Wieland occurs in the Cloverly formation of Wyoming. In this, however, the frond does not display the tendency to be divided into segments as do the Jurassic species.

Podozamites lanceolatus (Lindley and Hutton) F. Braun (Dawson, 1886, p. 6, Pl. 1, Fig. 3; Knowlton, 1907, p. 120, Pl. 14, Fig. 4; Berry, 1929, p. 45, Pl. 6).—So many specimens of widely different ages have been referred to this species that it now needs restudy before it can have much stratigraphic significance.

Zamites arcticus Göppert (Fontaine, 1905, p. 306, Pl. 73, Figs. 1–6).—The apical ends of the short, broad pinnules of this species are almost perfect semi-

circles, and the parallel veins number 7 or more. The species occurs in the Kootenay of Canada as *Z. montana* Dawson (1886, p. 7, Pl. 1, Fig. 6 only), and *Z. sp.* Dawson (1886, p. 7, Pl. 1, Fig. 4).—Seward (1926, p. 92, Pl. 7, Fig. 43) regards this and others as species of *Ptilophyllum*.

Zamites apertus Newberry (1891, p. 199, Pl. 14, Figs. 4, 5).—The rounded apical ends of the slender pinnules of this species are asymmetric, blunt-pointed, and bend forward slightly. The species occurs in the Canadian Kootenay as *Zamites acutipennis* Heer (Dawson, 1886, p. 7, Pl. 1, Fig. 5). It may be identical with *Zamites borealis* Heer from the Lakota sandstone of the Black Hills, and the Kome beds of Greenland. It is possible, therefore, that *Z. arcticus* Göppert and *Z. apertus* Newberry cross the unconformity.

Ginkgo arctica Heer (Berry, 1929, p. 48, Pl. 7, Fig. 6), identified as *G. siberica* Heer by Knowlton (1907, p. 124, Pl. 13, Figs. 1-4; Pl. 14, Figs. 1-2) and Dawson (1886, p. 8, Pl. 2, Fig. 1), and as *Baiera brevifolia* Newberry (1891, p. 199, Pl. 14, Fig. 3), occurs in both the Kootenay and lower Blairmore of Canada and in the Kootenai above the unconformity in Montana. Perhaps the specimens called *Baiera longifolia* Heer by Dawson (1886, p. 9, Pl. 2, Fig. 5), *Salisburia lepida* Heer (Dawson, 1886, p. 8, Pl. 2, Fig. 2), and *Salisburia nana* Dawson (1886, p. 8, Pl. 2, Fig. 3) from Martin Creek, also belong here. No *Ginkgo* has yet been reported from the Morrison below the unconformity; but species of *Ginkgo* are present in abundance at other supposed North American Jurassic localities, such as Douglas County, Oregon, and Cape Lisburne, Alaska. The absence of *Ginkgo* from the Morrison, therefore, apparently represents a facies difference and does not mean that *Ginkgo* was not in existence contemporaneously in adjoining regions.

Sphenolepis kurriana (Dunker) Schenk.—This conifer was illustrated by Berry (1929, p. 51, Pl. 8, Figs. 4-6) as *Athrotaxis grandis* Fontaine, from the Kootenay and lower Blairmore. To it doubtless belongs the fragment named *Cyperites* sp. by Dawson (1893, p. 91, Fig. 16) from Anthracite or Canmore; and it has been illustrated by Heer as *Cyparissidium gracile* Heer from the Kome beds of Greenland. It occurs, however, in the Morrison below the unconformity, at the coal outcrops 6 miles southwest of Geyser, Montana.

MISCELLANEOUS KOOTENAY SPECIES

Other species, said to be from the Kootenay of Canada, but not yet definitely identified from the Morrison, are the following.

Dicksonia sp. Dawson (1886, p. 5). Martin Creek.—This is very similar to, if not identical with, *D. concinna* Heer, a Jurassic species from eastern Siberia. The specimen was not illustrated.

Asplenium dicksonianum Heer (Dawson, 1886, p. 5, Pl. 3, Fig. 1). Canmore.—Specimens probably representing this species were found by W. A. Cobban in the Kootenai at Great Falls, Montana.

Angiopteridium canmoreense Dawson (1893, p. 83, Fig. 2). Canmore.—This species has been identified in the Shasta beds of California.

Pecopteris browniana Dunker (Dawson, 1893, p. 84, Fig. 3). Anthracite.—The identity of this fragment with *Pecopteris browniana* Dunker may be questioned. To it may, perhaps, be added the specimen identified as *Sphenopteris latiloba* Dawson (1893, p. 86, Fig. 6).

Cladophlebis falcata Fontaine (Dawson, 1893, p. 84, Fig. 4). Anthracite.—The relationship of this specimen seems to be with *C. f. montanensis* Fontaine, from below the unconformity in Montana.

Cladophlebis sp. Dawson (1893, p. 85). Anthracite.—Not illustrated.

Aspidium fredericksburgense Fontaine (Dawson, 1893, p. 85, Fig. 5). Anthracite.—Without examination of Dawson's specimen there is doubt whether it should be assigned to this species or to *Cladophlebis distans* Fontaine or *C. fisheri* Knowlton, which may be a form of *C. constricta* Fontaine, as previously discussed.

Ctenis albertensis Warren (1927, p. 48, Pls. 1, 2). Coal mine of the Canmore Coal Company at Canmore.—These specimens are parts of cycad fronds showing clearly the features of the original leaves. Warren regarded the species as having strong Jurassic affinities, particularly resembling species from Douglas County, Oregon. Although no similar fronds have been reported from any other supposed Lower Cretaceous strata of western North America, some fragments called *Ctenis imbricata* Fontaine, with anastomosing veins, were found in the Potomac group of the Atlantic Coastal Plain. The pinnules of these fragments are depicted as having strongly constricted bases, whereas those of *C. albertensis* are attached to the rachis by broad and decurrent bases. The species are, therefore, significantly different and probably not closely related.

Williamsonia? sp. Dawson (1893, p. 87). Anthracite.—Not illustrated.

Dioonites borealis Dawson (1886, p. 6, Pl. 1, Fig. 2). Martin Creek and Canmore.—*Anomozamites acutilobus* Heer (Dawson, 1886, p. 7, Pl. 1, Fig. 7) seems to be a short-lobed form of this species.

Sphenozamites sp. Dawson (1886, p. 7). Martin Creek.—Not illustrated.

Baieropsis sp. Dawson (1893, p. 87). Anthracite or Canmore.—These are fragments of uncertain identity and significance.

Leptostrobus longifolius Fontaine (Dawson, 1893, p. 88, Fig. 8). Anthracite or Canmore.—The specimen, as illustrated, gives little clue to its correct identity.

Pinus anthraciticus Dawson (1893, p. 89, Fig. 10). Anthracite.—This specimen, depicted as a pine seed, needs re-examination.

Pinus susquaensis Dawson (1886, p. 9, Pl. 2, Figs. 6, 6a). Martin Creek.—These specimens resemble species of *Czechanowskia*.

Sequoia smittiana Heer (Dawson, 1886, p. 9, Pl. 2, Figs. 7, 7a). Coal Creek.—*Taxodium cuneatum* Newberry (Dawson, 1886, p. 10, Pl. 2, Fig. 8) probably belongs here. These specimens apparently can be matched with *Sequoia acutifolia* Newberry (1891, p. 200, Pl. 14, Figs. 7, 7a) and coniferous leaves (Knowlton, p. 127, Pl. 12, Figs. 5, 6) from the Kootenai above the unconformity in Montana.

Cephalotaxopsis sp. Dawson (1893, p. 89). Anthracite or Canmore.—Not illustrated.

Sphenolepidium pachyphyllum Fontaine (Dawson, 1893, p. 89, Fig. 12). Anthracite or Canmore.—Of doubtful identity.

Sphenolepidium sp. Dawson (1893, p. 90, Fig. 13). Anthracite or Canmore.—Of doubtful identity.

Pagiophyllum sp. Dawson (1893, p. 90, Fig. 14). Anthracite or Canmore.—These leaves resemble those of species of *Nageiopsis*.

Carpolithes sp. Dawson (1893, p. 90, Fig. 15). Anthracite or Canmore.—Seeds or fruits of indefinite affinity.

CONCLUSION

Assessing the species listed from the enlarged Morrison of Montana and the Kootenay of Canada we find that many are recorded as new species; some apparently cross the unconformity into the Kootenai and lower Blairmore; and others are so fragmentary that their true identity and significance remain uncertain. Obviously this florule must be somewhat older than that found in the strata overlying the unconformity. The fact that many of the new species do not continue into the Kootenai and lower Blairmore floras, according to the more recently published studies of those floras, indicates a significant change of some sort. The environmental and depositional conditions apparently changed little, if at all, for the bulk of the described specimens of the Morrison, Kootenay, and lower Blairmore floras are from the shales associated with coal beds. On the other hand, the flora of the Kootenai above the unconformity in Montana is almost entirely from sandy shales not associated with coal beds, but this flora is practically the same as the lower Blairmore flora, except that it lacks the single dicotyledon, *Sapindopsis magnifolia* Fontaine (Berry, 1929, p. 64, Pl. 10, Fig. 8) now known from the lower Blairmore. Thus far no dicotyledons have been reported from the Kootenai, but they should be looked for.

Comparing the Morrison florule with others now generally regarded as Jurassic from Oroville, California, Douglas County, Oregon, and Cape Lisburne, Alaska, we find few species in common, although in gross aspect there are strong similarities. Several reasons may be given for the lack of greater specific correlation between these floras. First, they may come from Jurassic horizons of widely different ages. Second, the environmental conditions may have been considerably different, thus producing different facies. Third, although Fontaine described all these floras, thus presumably giving a high degree of accuracy in the cross-correlation of species, an inspection of many of the specimens involved reveals material that can hardly be described as characterizable. Berry's synonymies in the revision of the Potomac flora exemplify Fontaine's predilection to overspeciation. The need for a restudy of all these floras is apparent.

Foreign Jurassic floras, by Seward from England, by Laporta from Portugal, by Heer from Siberia, and by Wieland from Mexico, contain few if any species in common with the Morrison florule. A restudy of some of these floras may reveal closer affinities with those of the Western Interior, Pacific Slope, and Alaska,

than now suspected, and their exact stratigraphic position may become more precise.

The combined flora of the Kootenai and the lower Blairmore from above the unconformity contains so many species in common with known Lower Cretaceous floras—especially that from the Kome beds in Greenland—that a Lower Cretaceous age for them is generally acknowledged. This flora differs from that in the enlarged Morrison by at least these well characterized species: *Dryopteris montanensis* (Fontaine) Knowlton, *Cladophlebis browniana* (Dunker) Seward, *Sagenopteris mclearni* Berry, *Sagenopteris elliptica* Fontaine, *Chiropteris williamsi* Newberry, *Protorhipis fisheri* Knowlton, *Zamites montanensis* Fontaine, and *Sequoia reichenbachii* (Geinitz) Heer.

Of these, *Sagenopteris mclearni* Berry, *Chiropteris williamsi* Newberry, *Protorhipis fisheri* Knowlton, and *Zamites montanensis* Fontaine are especially distinctive. They apparently represent new developments, for they have never been reported from any Jurassic floras, although one could pick out Jurassic species that might be considered as ancestral to them. The fact that these assumed ancestors are absent from the Morrison of Montana and Kootenay of Canada may, like the similar absence of *Ginkgo* from the Morrison of Montana, be regarded as a facies difference in comparison with the Jurassic floras of California, Oregon, and Alaska, where some of them are present. If this be so, then it seems likely that in the time interval of the unconformity, evolution of some Jurassic forms elsewhere, particularly in the Pacific Coast region, produced these species, which by migration reached Montana and Alberta in time to be embedded in Lower Cretaceous sediments. The disputed strata below the unconformity, as a result of this analysis, may be considered at this writing as marked not by what they contain, but by the distinctive species absent from them.

The paleobotanical evidence as now known, therefore, seems to justify the inclusion of all the Morrison, enlarged up to the unconformity, in the Jurassic sequence. How much of the original Kootenay of Canada is equivalent to this Morrison remains to be seen after the fossils and strata there involved have been studied in more detail. The name Morrison, because of its long established use for a well defined lithologic unit containing a rich reptilian and mammalian fauna, should be retained at least in the United States, but the name Kootenay, as first proposed and now accepted in Canada, may, it seems, be retained without confusion for the Morrison equivalent there. As for the upper part of the unit now known as Kootenai in the United States and its equivalent in the lower Blairmore in Canada, a committee of geologists familiar with the strata and fossils involved should recommend a satisfactory new name.

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ORIGIN OF CONTINENTAL SHELVES¹

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ABSTRACT

In order to explain the common occurrence of a shelf edge at the isobath of 200 meters, a widespread subsidence of the shelf area in the order of 100 meters has to be assumed, apart from the influence of eustatic changes of sea-level. Spasmodically a warping or tilting movement has taken place along the continental border, causing a submergence of what formerly was the margin of the continent and a simultaneous bowing-up of a marginal tract parallel with the newly formed coast line. The most recent movements are revealed by the attitude of the marine terraces occurring along oceanic coasts in far distant regions. It is argued that the periodical action of convection currents, displaying themselves below the continental margin as a result of the existing distribution of sialic and simatic rocks in the border zone of continental and oceanic areas, accounts for the periodical movements along the marginal flexure of the continents. So, the phenomena of the continental margin are correlated with other periodic events occurring in the earth's crust and its substratum. Finally a section is devoted to the submarine canyon-like trenches which are incised in the shelf body. These features are classified in three groups. Theories involving a subaerial origin of the notched shelf edge are incompatible with data presently known about the geological history of the continental margin.

Almost everywhere the real edge of a continent lies below the level of the ocean. Generally a shallow platform borders the continent. Its edge lies about 200 meters below sea-level and an area of 10,000,000 square kilometers of the continents is thus covered by shallow shelf seas. What is the reason of this world-wide uniformity of depth of the shelf surface and its edge?

Echo soundings, geological and geophysical explorations carried out during the last decade have, moreover, revealed many features hitherto unknown about the morphology and structure of the shelf and its outward slopes. From these observations it appears that the history of the shelf was rather complicated. Sedimentation, abrasion, and denudation played their role. The area was subjected to changes of sea-level and movements of the bottom. Wind-waves and tidal currents acted upon the sediments of the shelf. The influence of each of these and still more factors in the building of the submerged part of the continental margin is still an open question.

The outward slopes of the shelves are notched by great valley-like trenches descending toward the abyssal depths of the ocean. The origin of these huge gullies is another problem that challenges us.

On the other hand, the region back from the coast offers a series of problems of its own. Characteristic of the marginal part of the continental land are widespread features of rejuvenation and a number of elevated marine terraces. By their prevalence in all latitudes along the continental border these phenomena are impressive and require an explanation which extends beyond local interest. How can these features be understood so as to form a harmonious supplement to those of the submerged part of the continental margin?

Generally the shallow platforms bordering the continents are classified in two

¹ Manuscript received, November 1, 1945.

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categories, namely, the inner and the outer shelves. The first group comprises such regions as the shelf of the North Sea and the Sunda Sea. Bathymetric charts show them to be furrowed by river-like trenches.

And indeed, in the two examples just mentioned their subaerial origin as rivers extending over these regions during low stands of the sea-level in Pleistocene time was clearly demonstrated by data furnishing converging evidence. Their course can be followed toward the debouchement of present-day rivers. Moreover, the frequent finding of remains of large vertebrates as far as Dogger Bank shows the North Sea to have been a land area in the near past. And in the case of the Sunda shelf the congruence of such animals as fresh-water fishes clearly proves, for example, the rivers of Western Borneo and East Sumatra to have been connected in sub-Recent time. The shelf of the Barents Sea is considered to belong to the European continent. In this area Spitsbergen and Bear Island portray the nature of structural units which, over large stretches were probably truncated and covered by the sea. So, between Spitsbergen and Scandinavia the inner shelf of the Barents Sea gradually passes toward the outer shelf of northwestern Europe. Here, too, the sea-bottom shows a drowned system of rivers. However, although highly interesting in many respects, the origin and history of the inner shelf regions is left out of consideration here, since they do not belong to the marginal zone proper of the continents.

According to Kossinna, the shelves all over the world cover 27,500,000 square kilometers, or 7.6 per cent of the surface of the oceans. The figure for the outer shelves is 9,900,000 square kilometers, or 3.1 per cent distributed as follows.

AREA OF OUTER SHELVES

	Sq. Km.	Percentage of Sea Surface
Atlantic Ocean	4.6	5.6
Indian Ocean	2.4	3.2
Pacific Ocean	2.9	1.7

The origin of the outer shelves is the problem to be considered in the following pages.

Extensive considerations on the origin of the outer shelf by the present writer are published elsewhere.³ The following lines contain a synopsis of the results obtained.

From the available data it appears that the gradation plane of the shelf's surface, so far as it is adjusted to present conditions, is formed as a surface gradually deepening from the coast to a depth of about 70 meters below sea-level. This figure is based on observations on the Atlantic and Pacific shelves of North America. For two islands in the southern Atlantic, Saint Helena and Ascension, a slightly higher figure—nearly 100 meters—seems to be the most probable estimate.

³ See a separate chapter in the second edition of: J. H. F. Umbgrove, *The Pulse of the Earth*, published by Nijhoff, The Hague.

Generally, however, the break of slope which is mostly called the edge of the shelf lies near the isobath of 200 meters. The question therefore, arises how the shelf surface between the isobath of 70 and 200 meters originated. In order to explain this situation the possible influence of eustatic changes of sea-level and movements of the bottom have to be examined.

At first it seems that the problem may be solved in a simple way by surmising the deeper part of the shelf surface to have been graded by submarine agencies during Pleistocene epochs of a lowered sea-level and to be adjusted to the existing hypsometric relation between sea surface and shelf surface. Although eustatic changes undoubtedly must be regarded as a factor of importance, the problem is more complicated. For, on both sides of the Atlantic the occurrence of coarse sediments and boulders were observed and these features bear undoubted evidence of their being originally deposited in the littoral zone.

Therefore, apart from eustatic changes (which during the Pleistocene may have caused the deposition of littoral deposits at a maximum depth of about 100 meters below present sea-level) an additional widespread subsidence of the bottom in the order of 100 meters should be assumed. According to Bourcart, the formation of the surface under discussion would date from Mousterian time. The same author recognizes a second surface along the oceanic slopes of the shelf at a depth of 200 to 100 meters, and a third between the isobaths of 500 and 1,000 meters, as noticed in many regions off the Atlantic coasts studied by him. Apparently, in the course of time the original continental margin has sunken deeply below the level of the sea. A prism of sediments (for the greater part erosion products from the continents) accumulated on it. Such a situation was revealed by the seismic-refraction measurements of Ewing, Crary, and Rutherford in the case of the sunken borderland Appalachia, which is now covered by a pile of shelf deposits ranging from Triassic to Recent and attaining a thickness of 12,000 feet at a distance of 60 miles off the present coast line.

In clear contrast to the positive shift of the shelf area, the land side of the continental margin shows widespread evidence of a bottom movement in the opposite direction, a zone parallel with the oceanic coast being characterized by rejuvenation of the relief. Chamberlin and Salisbury, and recently especially Jessen and Bourcart, paid attention to this phenomenon.

It was the last-named author who in 1938 advanced the theory of the continental flexure. Spasmodically a warping or tilting movement seems to have taken place along the continental border, causing a periodical submergence of what formerly was the margin of the continent and a simultaneous bowing-up of a marginal tract parallel with the newly formed coast line.

The most recent movement of the coastal tract is demonstrated by the elevation of marine terraces along the oceanic coasts. The situation of the Sicilian terrace at 100 meters above sea-level clearly shows that, apart from a eustatic shift (which would account only for a position of 40-50 meters at most above the present level of the sea), its emergence must be ascribed (certainly in part) to

warping of the bottom. This must have amounted to at least 50 to 60 meters in post-Sicilian, even post-Tyrrhenian, time provided that the Tyrrhenian terrace (30 meters above sea-level) can be correlated with the Yarmouth or Mindel-Riss interglacial stage.

Locally a more recent post-Mousterian tilting was noticed.

Gravity observations at sea carried out at right angles to the coast, generally show an increase in the isostatic anomalies of 30 to 100 milligals, when passing from the shelf to deep water. This rather sudden jump in the anomalies causes mostly positive values at the ocean side of the profiles. In total 26 complete profiles were obtained by Vening Meinesz on board of submarines of the Royal Netherlands Navy: three at the end of the Channel, one near Lisbon, four along the coast of West Africa, two near the mouth of Chesapeake Bay (east coast of the United States), four between Panama and San Francisco (one incomplete), six on the east coast of South America, two on the west coast of Australia, one on the south coast of Ceylon, and an incomplete one near Socotra.

From a study of several methods of isostatic reduction of the gravity stations, Vening Meinesz concludes that the most probable explanation of the data is to assume one or more of the sialic layers of the earth's crust rather suddenly thinning out at the continental margin.

Possibly the periodical action of convection currents, which are supposed to display themselves below the continental margin as a result of the peculiar distribution of sialic and simatic masses in the border zone of continental and oceanic areas, accounts for the periodical movements along the continental flexure. So, the phenomena of the continental margin probably are correlated with other periodic events occurring in the earth's crust and its sub-stratum.

The submarine canyon-like trenches which are incised in the outer slopes and—in places—in the surface of the shelf may tentatively be classified in three groups: (1) slightly ramified notches in the shelf edge extending down toward great abyssal depth, (2) gorges of the same type which, however, have headward extensions over the surface of the shelf, (3) submarine canyons showing a dendritic river-like pattern.

Near the shelf edge the trenches of the first group show a depth of 1,000 meters and more. In order to account for an erosion base at that level one would have to admit an oscillation either of the bottom or of the sea-level of at least 1,000 meters. However, such a hypothesis is incompatible with the data presently known about the geological history of the continental margin. Therefore, theories involving a subaerial origin of the notched shelf edge have to be abandoned. Hence, their formation must be due to submarine agencies. The gullies of the second group probably originated as oceanward extensions of large consequent rivers existing in Pleistocene and more recent time. During the Pleistocene and more recent modelling of the upper shelf surface the gullies probably were held open by submarine processes. The canyons of the third group probably formed in pre-glacial time under subaerial conditions. Subsequently, a subsidence of the

bottom caused them to become drowned. Afterward they were more or less completely filled with sediments and finally they were re-excavated by the same processes which modelled the furrows of group.

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GEOLOGICAL RECONNAISSANCE IN SOUTHEASTERN PERU¹

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ABSTRACT

This paper gives the results of a reconnaissance made by the writer across the Cordillera de Vilcanota and the Cordillera de Carabaya, both forming the Cordillera Oriental, and as far as Maldonado on the Madre de Dios River in southeastern Peru. As it is the first time that this part of Peru has been geologically investigated, it was possible to obtain interesting data on the geology, stratigraphy, and structure of this little-known part of the Andes.

The Cordillera de Carabaya is a rugged, snow-clad range. The elevation of the lowest pass, Abra de Hualla-Hualla, is 4,820 meters above sea-level. Toward the east the range drops in a short distance to an elevation of about 600 meters at Rio Nusiniscato. A complete traverse could be made across the Cordillera Oriental between Urcos and the valley of Rio Madre de Dios. The regional geology is largely represented by older, pre-Cambrian, metamorphic schists and quartzites, which are overlain by Ordovician slates. Upper Paleozoic brown-red shales and sandstones occur west of the section, at Urcos. At its eastern half, east of Quincemil, vast Tertiary plains extend. A remarkable feature of the section is the Araza gneiss underlying the Marcapata metamorphic rocks. The Araza gneiss appears to be early pre-Cambrian, probably Archean, in age. From the writer's knowledge of the South American Andes, it would seem that this is the first recognized occurrence of gneiss on the eastern slope of the Andes, since none is known to have been described from Colombia, Ecuador, northern Peru, or Bolivia.

Structurally, this part of the Cordillera Oriental appears to be block-faulted. The faulting is normal; there is no evidence of large-scale thrusting.

INTRODUCTION

Geological investigations of a general character between Cuzco and Maldonado, on the Madre de Dios River, in southeastern Peru, were carried out by the writer in December, 1943, as part of the program for the preparation of a geological map of Peru. The reconnaissance was made for the Instituto Geológico del Perú and formed part of a general geological study of southeastern Peru entrusted to the writer, as head of a geological mission organized for this purpose.

Besides the works of Bowman,³ Gregory,⁴ Douglas, 1920,⁵ and E. Maldonado,⁶ dealing with the region of Cuzco and some neighboring areas, the only published record of original field investigations in the region in which the writer made his reconnaissance is the paper of J. A. Douglas and O. M. B. Bulman of 1933.⁷

¹ Manuscript received, November 2, 1945.

² Consulting geologist.

³ I. Bowman, *The Andes of Southern Peru, Geographical Reconnaissance along the 73rd Meridian* (New York, 1916).

⁴ H. E. Gregory, "Geologic Reconnaissance of the Cuzco Valley, Peru," *Amer. Jour. Sci.*, Vol. 41 (New Haven, Connecticut, 1916).

⁵ J. A. Douglas, "Geological Sections through the Andes of Peru and Bolivia," *Quar. Jour. Geol. Soc.*, Vol. 76 (London, 1920).

⁶ E. Maldonado, "Contribución al estudio de la Geología de Sicuani," *Rev. Universitaria*, Año XIII (Lima, 1918).

⁷ J. A. Douglas, "The Geology of the Marcapata Valley in Eastern Perú, with Appendix on the Graptolites from the Quitari Area by O. M. B. Bulman," *Quar. Jour. Geol. Soc. London*, Vol. 89, No. 355 (1933), p. 3.

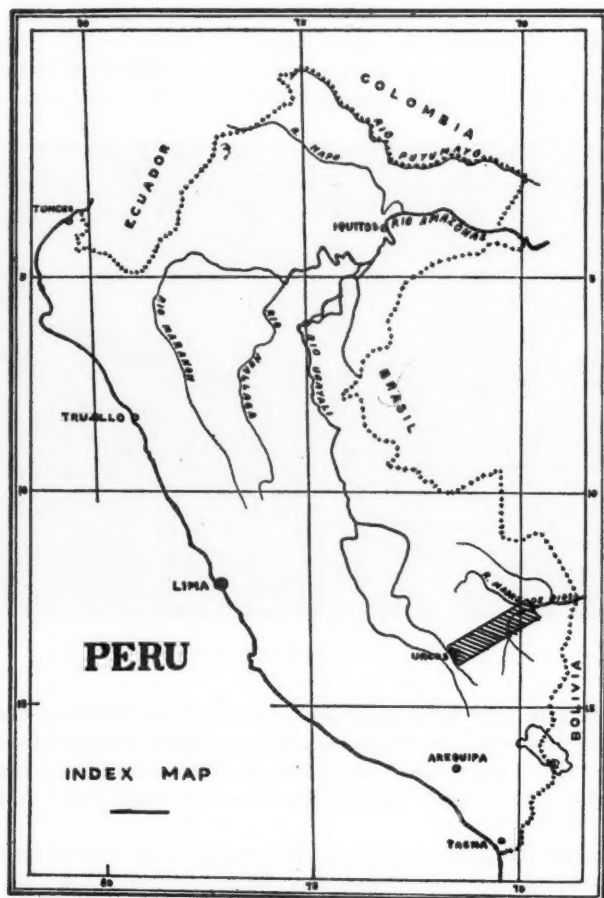


FIG. 1.—Index map of Peru, showing area of reconnaissance.

A recently opened highway crossing the region of the high mountains from Urcos and almost down to the Oriental Plains (Montaña) facilitates geological observation, which can now be made for the first time and which formerly would have been considerably more difficult to accomplish.

In the writer's section, from Rio Nusiniscato to Rio Inambari, his assistant, I. Tafur, gathered samples which were examined and determined by the writer. From the mouth of Rio Inambari and down to the confluence with Rio Tambopata, where the village of Maldonado is situated, personal field observations were



FIG. 2.—Hualla-Hualla Pass with snow peaks.

carried out again. The writer also flew over the whole region at low altitude. Flights were also made from Maldonado back to Cuzco, as well as from Maldonado to the Ucayali basin, along the Madre de Dios valley and the eastern front of the Andes. These flights amply complement the field observations on the ground.

Fossil material found in the region was very scanty, as most of the formations are early Paleozoic and older in age; thus, the age determination is based mainly on the stratigraphic position of the different formations, their correlation as compared with known rocks of similar character in the neighboring areas, and in many places, the relative degree of metamorphism.

The writer wishes to express here his thanks to J. A. Broggi, director of the Instituto Geológico del Perú, through whose kind collaboration the reconnaissance and the publication of its results were made possible.

PHYSIOGRAPHY

The physiographical features of the area under study are complicated by several high and rugged mountain ranges which form the Cordillera Oriental, southeast of the headwaters of the Upper Rio Urubamba. The high Cordillera Real of Bolivia extends northward into Peru and this, joining a traverse range, the Cordillera Collao, forms the Vilcanota Massive (Nudo de Vilcanota). From this, in turn, extend two independent ranges, the Cordillera de Vilcanota, which is cut by the Urubamba River at Pongo de Mainique, and Cordillera de Cara-



FIG. 3.—Middle course of Rio Madre de Dios seen from the air.

baya, northeast of the Cordillera de Vilcanota, which is an independent, high, snow-covered range with peaks up to 6,000 meters. The two ranges are crossed by the highway from Urcos to Quincemil, at the Abra Cuyuni, at 4,180 meters, and Abra Hualla-Hualla, at 4,820 meters. At Rio Nusiniscato, east of Quincemil, the elevation of the foothills drops to 600 meters; the easternmost front ranges of the Andes appear on the upper Rio Inambari at Punquiri, which is also the limit for canoe navigation on that river. Northeast of Punquiri and down the Rio Inambari as far as the borders of Peru with Bolivia and Brazil, there extend the vast plains of the Rio Madre de Dios.

The mountain ranges of this part of Peru have been relatively little investigated. Most of the known maps of the region diverge considerably in nomenclature and interpretation of the different mountain chains. The highest peak of the region is the Nevado de Azongate, at about 6,500 meters.

The only relatively complete studies of the high Cordillera known to have been carried out in the region, besides those of Douglas,⁸ are those by Bowman⁹ and the Peruvian-Bolivian Boundary Commission in 1911; the latter are limited to a narrow strip of boundary territory.

The Cuzco basin proper has been surveyed in some detail by Yale University's Peruvian Expedition in 1912, in which Gregory¹⁰ took part. Similarly, detailed physiographical data are given in Bowman's¹¹ reconnaissance along the 73rd Meridian.

Seen from the air, the region east of the Cordillera appears as a succession of



FIG. 4.—Rio Madre de Dios seen from the air.

parallel, high and sharp ranges, gradually lowering toward the northeast, and ending in chains of rolling parallel hills at the edge of the plains. The jungle-covered flat plains extend eastward as far as the eye can reach.

The vegetation of the region of the traverse ranges from Arctic, at the foot of the glaciers, at about 5,000 meters, to dense tropical in the valley of the Rio Madre de Dios.

GEOLOGY

The geological constitution of the high Andean part of southeastern Peru consists largely of early Paleozoic to pre-Cambrian rocks. In outline, the region

⁸ J. A. Douglas, *op. cit.*

⁹ I. Bowman, *op. cit.*

¹⁰ H. E. Gregory, *op. cit.*

¹¹ I. Bowman, *op. cit.*

east of Urcos or northeast of the Rio Vilcanota, is similar to the Cordillera Real of Bolivia, of which it is undoubtedly a continuation. However, exposures of gneiss and older metamorphic rocks associated with it are suggestive of basement rocks of the Andes. In contrast to the high Cordillera proper, Mesozoic and younger sediments occur in the area between Urcos and Cuzco, and vast extensions of younger Cenozoic formations cover the plains east of the Andes. The present geologic sketch refers only to the geology between Urcos and the Madre de Dios River. For the geology of the Cuzco area proper, the work of Gregory should be consulted.

PRE-CAMBRIAN

Araza gneiss.—This is a gneiss occurring between Kilometers 278 and 288, along the road from Cuzco to Quincemil and near the bridge across the Rio Araza.

The gneiss is light gray in color, with large biotite flakes. It is traversed by quartz veins and overlies a granite batholite. In turn, the gneiss is overlain by a very widely distributed formation of phyllites and mica chists injected with granites. The gneiss of Araza is a basal and older formation and could be considered Archean in age. Some of the gneisses of the region have been described in detail by Douglas.¹² To the writer's knowledge, the gneiss of Araza is the oldest occurrence of its kind in the eastern Andes. None of the traverses across the eastern Andes of Colombia, Ecuador, northern Peru, or Bolivia has disclosed this, apparently oldest core. Similar migmatic gneisses are, however, known and were observed by the writer in the Cordillera de Merida in Venezuela¹³ and are described by Windhausen¹⁴ from the northern main Cordillera del Norte in Argentina. In the case of the Araza gneiss, as well as in the aforementioned occurrences, the gneisses are also injected by granites and underlie pre-Cambrian metamorphics.

Marcapata formation.—This widely distributed and well developed metamorphic formation is composed predominantly of phyllites, varying in color from dark gray to reddish violet and greenish, that appear interbedded with light-colored quartzites and here and there interpositions of mica schists. It appears in two separate areas of the traverse. The first area of these metamorphic rocks extends along the axis of the Cordillera de Vilcanota, between the Abra de Cuyuni and the headwaters of the Rio Paucartambo, east of Acongate, or approximately between Kilometers 87 and 143 along the main road from Cuzco. The second metamorphic area extends along the eastern steep flank of the Cordillera de Carabaya, toward the east, and below the Hualla-Hualla Pass, or between kilometers 222 and 278 along the same road. Here, the metamorphic rocks of the Marcapata formation extend all along the upper Rio Marcapata and distinctly

¹² J. A. Douglas, *op. cit.*

¹³ V. Oppenheim, "Contribution to the Geology of the Venezuelan Andes," *Bol. Geol. Min. T.I.*, Nos. 2, 3, 4 (Caracas, 1937).

¹⁴ A. Windhausen, *Geologia Argentina* (Part II). Jacobo Peuser, Buenos Aires (1931).

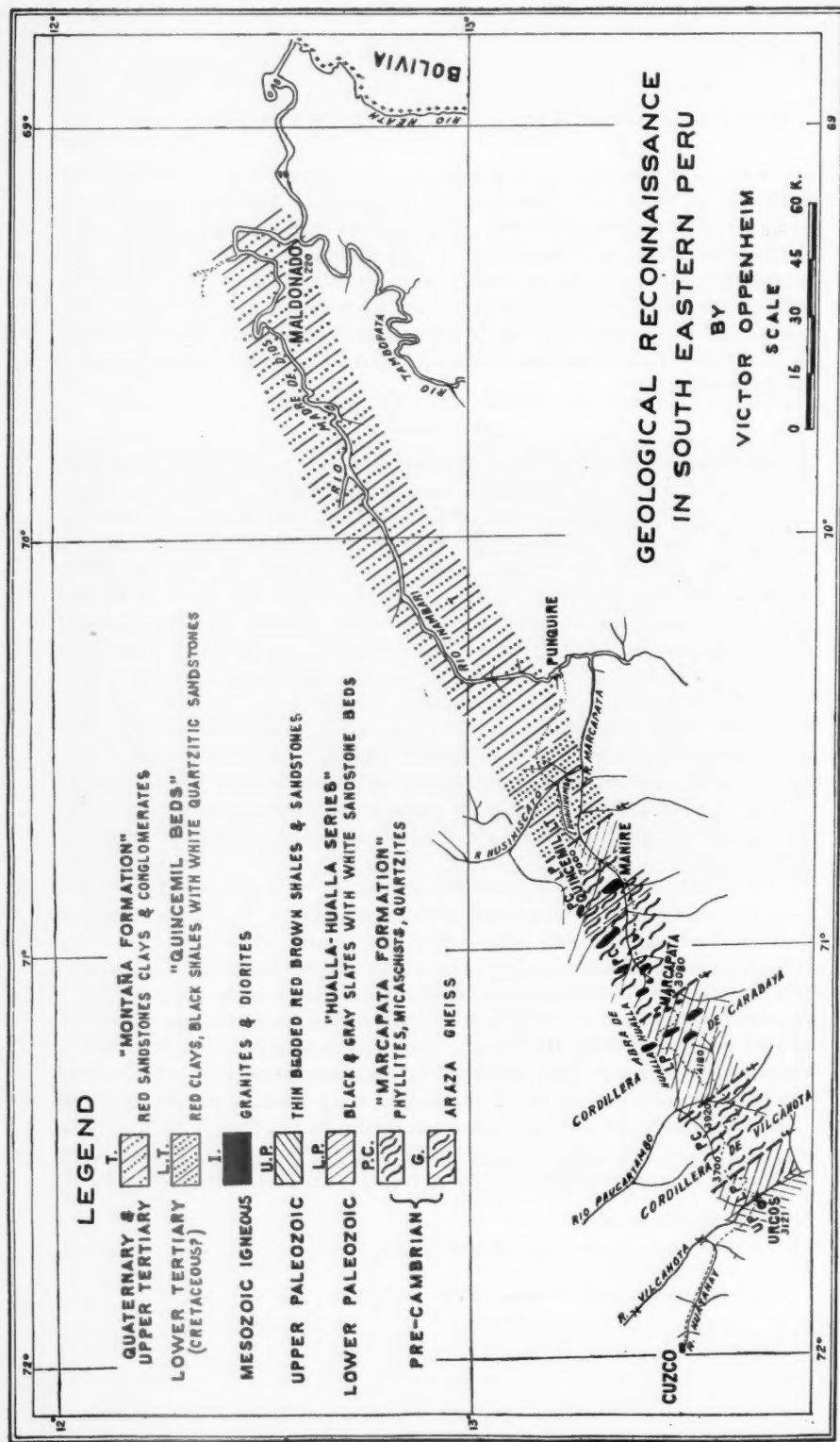


FIG. 5.—Geological reconnaissance in southeastern Peru.

overlie the Araza gneiss. The phyllites and quartzites of the Cordillera de Carabaya are intensely affected by a great number of granitic intrusions. The granites are mostly light gray in color. Given the position of the Marcapata formation, overlying the Araza gneiss, the writer is inclined to consider it possibly Algonquian in age. Structurally, the Marcapata formation is intensely folded, contorted, and faulted, making any attempt at stratigraphical subdivision practically impossible. The formation can be estimated at no less than 1,500 meters thick. The Marcapata formation, as observed in the first area in the Cordillera de Vilcanota, similarly to that occurring in the Cordillera de Carabaya, consists of phyllites and quartzites identical with those found along the valley of the Rio Marcapata, yet granitic intrusions do not seem to occur here and probably are wholly absent.

LOWER PALEOZOIC

Hualla-Hualla series.—As this series of sedimentary rocks is best developed at the Hualla-Hualla Pass, the writer designates it by the same name. It appears overlying unconformably the metamorphic Marcapata formation and consists of a widespread series of slates and shales of a dark gray to deep black color. The slates are associated with beds of light-colored quartzites, hard and fine-grained. The strata are folded and faulted, and, in the Hualla-Hualla Pass or along the crest of the Cordillera de Carabaya, are traversed by large intrusions of granites. These are evidently younger than the slates and have been intruded along lines of regional structural weakness. Thus, the snowclad peaks at the northwest and southeast of the Pass are granite laccoliths. As it was not possible to follow the structural pattern of this series, its thickness can, therefore, only be estimated; this could be of the order of 2,000 meters.

Vague fossil fragments were found in some of the Hualla-Hualla slates; these were not clear enough, however, to enable an age diagnosis to be made. By comparison, it can be accepted that the Hualla-Hualla series is Lower Paleozoic, probably Ordovician in age.

UPPER PALEOZOIC

To the sediments of Upper Paleozoic age the writer is inclined to attribute the strata of red-brown sandstones and shales appearing west of Urcos. Overlying unconformably the Hualla-Hualla slates, they can be correlated with the Devonian fossiliferous strata described by E. Maldonado¹⁵ from the Sicuani region.

MESOZOIC

The formations exposed in the proper Cuzco basin and the Vilcanota Valley have not been the object of the writer's study. However, a general field view suggests that the original classification by Gregory¹⁶ of his Pachatuca formation,

¹⁵ E. Maldonado, *op. cit.*

¹⁶ H. E. Gregory, *op. cit.*

Molle-Orco conglomerate and the Huallabamba formation as Mesozoic, in general, seems to be correct as far as the stratigraphic position of these beds is concerned, since they underlie the fossiliferous Cretaceous Yucay limestone.

CENOZOIC

LOWER TERTIARY

Quincemil beds.—At about 3 kilometers east of Quincemil along the main road to Rio Nusiniscato, there appears first a thick succession of gray shales and thin red clays interbedded with red and white hard sandstones. These red strata, which the writer names the Quincemil beds, appear to be intensely folded and faulted, exposing steep dips and in some places vertical bedding. They seem to represent the same red beds described by Douglas from the Rio Huallumbe area.

At Rio Nusiniscato, near Limonchayo, about 20 kilometers from Quincemil, the strata show the sandstone facies and appear in a succession of hard quartzitic sandstone beds almost standing vertically.

The Quincemil beds should be found to be fossiliferous upon closer examination. Based on comparison with similar strata found by the writer in Caupolicán, in the neighboring region in northeastern Bolivia, as well as on the descriptions by Douglas,¹⁷ the writer would attribute to the Quincemil beds a Lower Tertiary or possibly an Upper Cretaceous age, in accordance with Douglas' estimate.

The brevity of the reconnaissance and the intensely faulted and folded strata did not permit the measurement of the thickness of these beds.

A distance of about 10 kilometers in a straight line separates the valley of Rio Nusiniscato from the last elevations of the broad and open valley of Rio Inambari. Although the writer did not cover this part of the traverse personally, from the samples collected by his assistant as well as from descriptions and flights across the area, he assumes that the same Quincemil beds extend to the very Andean foothills, where they are overlain by younger Tertiary sediments.

UPPER TERTIARY

Madre de Dios formation.—The whole valley of the Rio Madre de Dios from the mouth of Rio Heath, forming the Peruvian-Bolivian boundary, and up to Rio Inambari, as well as the whole lower valley of the latter river are made up of a thick succession of young Tertiary sediments appearing ordinarily in isolated outcrops along the high river banks. These are, in a descending succession, the following.

- Red clays
- Reddish sandstones
- Lenticular beds of coarse conglomerates of basement rocks up to about 3 meters thick
- Marly mottled or reddish clays with a few concretions
- Gray-blue or greenish clays and sandstones of rather coarse texture

The outcrops are very few and appear only well exposed during the season

¹⁷ J. A. Douglas, *op. cit.*

when the rivers are low. The highest river banks are about 15 to 20 meters high. The exposed beds are very slightly tilted. At Pastora, above Maldonado, the beds show an average dip of 3° – 5° S. The age of these strata, which the writer names the Madre de Dios formation, probably ranges from Middle Tertiary to Pliocene-Pleistocene.

As could be observed from studies farther upstream along the Rio Madre de Dios and across the Fitzcarrald Pass at the headwaters of Rio Manu, this formation is several thousand meters thick. Its thickness in the lower valleys, however, could not be determined.

Seen from the air, the country appears flat over great expanse of territory beyond the Rio Madre de Dios Valley proper and its tributaries, showing here and there red clay and sandstone banks of the Madre de Dios formation; this appears to be extremely widespread in the southeastern part of Perú.

Higher ground seems, however, to occur farther east.

TECTONICS

The structural character of southeastern Peru is complex and would require a special study of its own. Based, however, on the field observations in the area between Cuzco and Maldonado, a tectonic outline can be drawn here which could be considered as characteristic of this part of the country.

As already shown, the rocks composing the Cordillera de Carabaya and the Cordillera de Vilcanota are almost wholly pre-Cambrian and Paleozoic in age, intensely folded and faulted. The formations show a distinct relation to each other in stratigraphic position, since they are separated by definite unconformities. Based on this evidence, several diastrophic cycles can be outlined in the geological development of this part of the Andes.

Huronian cycle.—This cycle succeeded the multiple Archean and pre-Cambrian foldings of a universal character, and is reflected in the intensely contorted and folded metamorphosed and igneous rocks of the Marcapata formation.

We can thus consider the Marcapata metamorphics as being affected by Huronian diastrophism, accepting that they overlie unconformably the pre-Cambrian Araza gneiss.

Caledonian cycle.—The folding and igneous intrusions which are related to the early Paleozoic Hualla-Hualla series took place during this cycle. An unconformity separates the deposition of this series from the overlying Upper Paleozoic beds.

Further, in the Andean section, there is a complete hiatus of post-Paleozoic formations and this can be attributed either to non-deposition or to subsequent erosion. The folded Mesozoic formations in the Andean plateau, west of the traverse, show a great thickness of marine sediments deposited beyond the old Carabaya Massive.

Laramide cycle.—The folding and intense shattering of the Yucay limestone

series of Gregory¹⁸ are due to diastrophic movements which occurred in late Cretaceous time, which also folded the underlying Mesozoic sediments of the Cuzco basin.

Andean cycle.—This coincided undoubtedly with the early Tertiary intense diastrophism of a broadly continental character. However, due to lack of sediments of that age in the highland part of the area under study, we must assume that early Tertiary sediments were largely eroded before the deposition of the Plio-Pleistocene San Sebastian lacustrine beds of Gregory. Their undisturbed, almost horizontal position in the Cuzco basin clearly indicates that during their deposition and until the present day, there was no tectonic activity in that part of the Andes. However, the folded and faulted young Tertiary beds of the eastern Andean foothills in the Madre de Dios valley are indicative of the effects of a large-scale orogenesis along the sedimentary belt bordering the great Andean Massive on the east.

The numerous intrusive and extrusive igneous rocks in the area under study can be attributed to very different ages. Some of the granites associated with the pre-Cambrian Araza metamorphic rocks are probably Archean in age. However, a great many granites and granodiorites, such as occur in the Hualla-Hualla Pass in the Cordillera de Carabaya, may be Mesozoic in age. The diorites near Cuzco may be pre-Mesozoic. The largest part of the basalts, andesites, and lava flows in the highland area between Cuzco and Urcos are probably early Tertiary to Mesozoic in age.

Structures.—The structural trend of the whole area is distinctly northwest and southeast. Large and broad folds are visible between Cuzco and Urcos and can be followed for considerable distances if observed from an aeroplane.

The intensely folded formations of the Urcos-Nusiniscato section show a series of northwest-southeast trending faults. Igneous intrusions occur commonly along these fault lines, east of the Hualla-Hualla Pass. The regional faulting is normal and block faulting seems to be the main tectonic characteristic of this part of the Andes.

¹⁸ H. E. Gregory, *op. cit.*

RESEARCH NOTES

INTERIM REPORT OF RESEARCH COMMITTEE¹

S. W. LOWMAN²
Houston, Texas

Mr. President, members of the Pacific Section, and guests.

Some of you may have seen the statement of research committee activities that was published in the October *Bulletin*. If so, you may recall that we have two specific objectives: first, to complete a reconnaissance survey of research in petroleum geology and allied sciences with explicit reference to exploration; and second, to formulate a comprehensive research program, which the Association may adopt as its recommendation for that research which is most needed to improve our ability to find oil.

With these objectives in mind, five subcommittees have been organized and are now making surveys of stratigraphy and sedimentation, tectonics, reservoir fluids, geophysics and geochemistry, and borderland fields of production engineering.

Three other subcommittees will duplicate, in part, the work of the first five, but they will do so from different points of view and should thereby furnish useful checks. These subcommittees are called research facilities, projects areas, and discovery thinking. Their functions have been described in the October *Bulletin* and need not be re-described here.

The first report of these subcommittees will be made January 15, so that I am not in a position to report on their progress at the present time.^{3a}

There are, however, two general lines of research-committee activity with which I have been more directly connected and which might be of some general interest to you. The first of these is an attempt to clarify some of the terms that are most often used in discussing the value of research projects; the second concerns suggestions as to the general features of our final program.

I have tried to clarify my ideas and to work out compromise definitions of a few terms which are commonly used in talking about research, in the hope that, when the committee convenes for round-table discussions, there may be general agreement, or agreement to disagree, about these meanings and thereby reduce misunderstanding and waste of time.

MEANING OF RESEARCH

In the first place, there is a notable lack of uniformity in the use of the word research. This confusion may be due to the use of a general-purpose word to describe a special scientific process.

The word research as we all know, but sometimes forget, is a common English word which dates from the Middle Ages, and has picked up many shades of meaning along the way. I have made an investigation of its meanings as recorded in the titles of popular periodical literature for the last 140 years, spot-checked by reading the more interesting-sounding articles.³ I believe that it is fair to say that some of the more common misconceptions of the last century persist as subsidiary implications up to the present time and crop up in unexpected places.

¹ Based on address delivered before the Pacific Section of the American Association of Petroleum Geologists at Los Angeles, November 8, 1945. Manuscript received, December 22, 1945.

² Chairman, A.A.P.G. research committee. Shell Oil Company.

^{3a} Progress reports have subsequently been received and are being studied.

³ A classification of popular articles since 1890 is shown in Table I.

Since the first World War, with its great boom in industrial research, the public has become increasingly conscious of research as "an intelligent and systematic way of getting things done." Housewives do "research" on home economics and school children do "research" on social studies. Whether scientists like it or not, the word belongs to the people. Research is popular and has all the draw-backs as well as the benefits that go with popularity. It has been suggested to me that we should abandon the term and invent or adopt some other. This I feel sure we will not do. The very popularity of the word research makes

TABLE I
ARTICLES ON VARIOUS KINDS OF RESEARCH LISTED IN READERS GUIDE
TO PERIODICAL LITERATURE 1890-1945*

Kinds of Research	1890-1894	1895-1899	1900-1904	1905-1909	1910-1914	1915-1918	1919-1921	1922-1924	1925-1928	1929-1932	July June 1932-1935	July June 1935-1937	July June 1937-1939	July June 1939-1941	July June 1941-1943	July May 1943-1945
Aeronautical										6	9	5	11	16	10	14
Agricultural																
Biological				5	6	10	5	10	17	10	19	11	9	10	10	10
Botanical																
Cancer																
Chemical																
Educational																
Engineering																
Food																
Historical																
Home Economics																
Industrial																
Medical																
Nutritional																
Physiological																
Radio																
Research (in general)																
Scientific																
Social																
Total	8	13	14	75	114	176	117	174	298	297	299	256	260	307	237	240

* This is not a complete list but it includes most items. Psychological research is the only major item of popular interest purposely excluded. Increase in popular interest in research due to the foundation of (A) the Rockefeller Institute, (B) the Carnegie Institution, (C) the beginning of World War I, and (D) depression.

it a powerful ally, because that popularity extends to stockholders and management. We are not seeking cloistered-hall seclusion; what we want is help in accomplishing our objectives.

SCIENTIFIC RESEARCH

If we need to be more specific, we can use some such term as scientific research.⁴ The earliest discussion of scientific research that I know of by a geologist was presented by G. K. Gilbert in 1886⁵ and 1887,⁶ and the following definition contains my understanding of his discussions. I offer it for your consideration.

Scientific research is the use of the scientific method directed toward the solution of a

⁴ Used in a broad sense to include all scientific research including industrial research, not in a special sense opposed to industrial research.

⁵ G. K. Gilbert, "The Inculcation of Scientific Method by Example, with an Illustration Drawn from the Quaternary Geology of Utah," *Amer. Jour. Sci.*, Vol. 131 (April, 1886), p. 284.

⁶ ———, "The Special Processes of Research," *ibid.*, Vol. 133, No. 198 (June, 1887), pp. 452-78.

problem concerning the relationship of facts (used here as concepts based on observational data). It consists of definition of objective; preliminary classification of antecedent knowledge with respect to the objective; formulation of working hypotheses; plan of investigation with respect to limiting conditions; selection of methods and techniques by analogy with previous investigations; collection of data; reduction of data and testing of hypotheses by the same procedures as above. This is continued until a relationship or relationships are found which satisfy all the conditions of the problems, or until one of the limiting conditions has terminated the investigation.

A catch-word definition of research might be "a combination of experience, judgment, common sense, and method applied to problems which contain too many variables to be solved by the first three alone."

FUNDAMENTAL RESEARCH

In talking about the kind of research that would be most desirable to include in our program, we use the terms "fundamental," "long-range," "significant," and "wide-scope." I have therefore attempted to understand these factors as the bases of classification and evaluation of research projects.

The most frequently used of these four terms is "fundamental" and I am sure that we would all subscribe to "fundamental research"—especially if we could evaluate it quantitatively. There are at least three pairs of contrasting terms which have been used as catch-words to indicate the fundamental and non-fundamental character of research. These are:

"Fundamental" vs. "hack" research as used by Donald C. Barton⁷

"Scientific" vs. "background" research as used by Isaiah Bowman⁸

"Vertical" vs. "horizontal" research as used by Henry R. Aldrich⁹

To the best of my understanding all three pairs of these contrasting terms refer to the end-points of a ratio which is the ratio of newly discovered scientific relationships to the total facts used in the investigation.

If neither the facts nor the relationships are new, it is not research, but compilation. If the facts are new but the general relationships are known, the research is said to be "hack," or "horizontal," or "background."

The research becomes increasingly "fundamental," "scientific" (Bowman), or "vertical" as the ratio of new relationship to total facts increases. Reclassification of old data in search of new scientific relationship is research with the laboratory stage left out. There is another form of research for which the catch-word "strategic" may be used and which is the most fundamental of all. It is the classification of known relationships in the search for new relationships of still wider scope and more general application.

Catch-words are useful if they do not replace more exact ideas. I suggest that it would be useful to describe research work in terms of (1) compilation of antecedent knowledge, (2) collection of new data, and (3) organization of the data and search for new scientific relationships.

⁷ D. C. Barton, "The State of Geologic Research in the Oil Industry," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 5 (May, 1937), pp. 665-74.

⁸ Isaiah Bowman, chairman, "Report of the Committee on Science and the Public Welfare," in *Science—The Endless Frontier: Report to the President on a Program for Postwar Scientific Research*, by Vannevar Bush, Director of the Office of Scientific Research and Development (July, 1945), pp. 75-77.

⁹ H. R. Aldrich, secretary, *Interim Proceedings of the Geological Society of America*. Pt. 2 (August, 1945).

INDUSTRIAL RESEARCH

There is one other term which touches our work rather closely and the meaning of which I have investigated to some extent. That term is "industrial research." Many writers define it in terms of utilitarian motive, aim, or objective. As such the term adds nothing to our discussion, because we have already described our work as being directed towards specific utilitarian objectives. However, the term is not harmless because it has many subsidiary implications and these may lead to confusion unless clearly expressed. Since we can express the central thought without the attendant implications, I suggest that we do not need to refer to our program as "industrial research." I further suggest that we can use the ideas "scope" and "time" and "significance" to classify our projects with respect to our objectives, rather than including these ideas in a general basket term like "industrial research."

Time is emphasized by many of those who write about industrial research. C. F. Kettering,¹⁰ of General Motors, says

"In our particular line, we work from ten to fifteen years ahead of the product. We call that research."

R. R. Morse¹¹ on the other hand, points out that in exploration,

"The existing body of facts and laws is great, it is the application which lags; . . ."

" . . . Our specific objective is to build our inventory of crude-oil reserves *now*, not 15 years hence."

This difference is probably due first of all to the urgency of the needs of exploration and second, to the small amount of unused knowledge in physics. I. I. Rabi,¹² chairman of the department of physics at Columbia University, states that applied physics has caught up with pure physics. In this field the explorer and the pioneer join forces in search for new lands. In exploration geology, on the other hand, there is still plenty of open range left—the gap between available knowledge and applied knowledge has not been closed. A considerable portion of informed opinion subscribes to the idea that our greatest need in geologic research is rigorous thinking about the data we already have. Levorsen's article on the Oklahoma City field is cited as an example.

PROPOSED EVALUATION OF RESEARCH

These considerations suggest that the evaluation of research projects may be based on estimation of the following values.

Urgency

Relationship of proposed investigation to relative scale of needs

Probability of Solution

- A. Nature of problem
- B. Volume of available facts and relationships
- C. Comparison with similar problems the solution of which is known

Estimated Cost

- A. Additional data needed
- B. Term of investigations
- C. Cost for unit of time

¹⁰ C. F. Kettering, discussion in *The Future of Industrial Research*, Standard Oil Development Company (1945), p. 69.

¹¹ R. R. Morse, "Outlook for Research in Exploration," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 8 (August, 1945), p. 1205.

¹² I. I. Rabi, "The Physicist Returns from the War," *Atlantic Monthly* (October, 1945), pp. 107-14.

Estimated Value

- A. Term of investigation as an inverse function of value
- B. Scope—Field covered and uniqueness of advantage to be gained. (From A.A.P.G. this would be interpreted in terms of fluid earth hydrocarbons as compared with total fuels or other fields of competition. For instance, chlorophyll synthesis, which might lead to direct manufacture of petroleum products, would be of great interest to oil companies, but would not be a research project for A.A.P.G.)
- C. Significance—The importance of the problem solved plus new leads suggested
- D. By-products—These in general can not be foreseen. However, in a properly conducted investigation by-products will occur, and sometimes are of greater value than the original objective. Paradoxically, therefore, although incalculable, by-products must be taken into consideration in our calculations. In general, it seems probable that long-range fundamental research would produce by-products of widest scope and possibly greatest significance.

RESEARCH CHARACTER OF INVESTIGATION

If the definition of research given in the early part of this discussion is acceptable then it would appear that the research committee is engaged in research on ideas, or a closely analogous investigation. And, if this is so, it should be profitable to investigate further the bases on which that definition is founded.

Gilbert¹⁹ described the processes of research as follows, using William Morris Davis' study of New England thunderstorms as an example.

In the first place, there was a certain amount of antecedent knowledge with respect to the subject of investigation, and this determined a large portion of the schemes; . . . In the second place, certain hypotheses were entertained in regard to the phenomena; . . . In the third place, analogy with other researches had its influence; . . . Finally numerous features of the system were determined by what may be regarded as obstacles to observation. . . .

The preliminaries having been arranged, observations were made during the summer of 1885, and the records of observation were placed in the hand of Professor Davis for the purpose of what is variously called "reduction" or "working up" or "digestion" or "discussion." What he did was to classify them in various ways, and observe the relations brought to light by the classification. But before he made a classification it was necessary to select a basis. [There were] in all no less than twenty categories of items, and each item connected with a place and a time. The number of possible arrangements was indefinitely large . . . From this bewildering array of possibilities, it was necessary to make a selection, and there was small probability that a random choice would lead to a profitable result. . . .

If then our interpretations are correct, the bases of classification, like the methods of observation, sprang from analogy with other researches, from previous knowledge of the subject in hand, and from hypotheses in regard to the results, and were conditioned by obstacles.

The investigation chosen by Gilbert as example for his discussion belonged to that class in which there are three sharply defined parts that follow in chronological sequence. These are: first, preliminary formulation of plan; second, collection of data; and, third, classification of data and observation of relationships. Gilbert, however, takes notice of the more common type of problem in which collection and classification of data proceed by alternating stages, as follows.

. . . , for it is a common feature of researches that the preliminary results determine the scope and field of subsequent observation. A research is an exploration of an unknown land and neither the route nor the goal can be foreseen. The explorer climbs the hill before him and from the vantage of its summit selects the most promising course for the next stage of his journey.

There are numerous practical difficulties in applying these considerations to a specific problem. These difficulties also were discussed by Gilbert.

This classification of considerations controlling the organization of research is believed to be comprehensive, and applicable to any other systematic research, but it will not serve the purpose of dividing into groups the details of working plan to which considerations give rise, because nearly

¹⁹ G. K. Gilbert, *op. cit.* (1887). Gilbert is quoted so extensively because his discussion is a concise, complete and logical statement of the ideas that have been expressed in recent conferences and appear to be current in modern scientific thinking.

every detail is the joint product of considerations falling in two or more categories; and it should be observed also that its categories are not mutually exclusive. The consideration of obstacles—or practical limitations—never occurs alone, but merely modifies the procedure indicated by other considerations. The consideration of analogy cannot stand alone, because analogy exists only in virtue of some knowledge or supposed knowledge or hypothesis with reference to the nature of the subject of research. And again, considerations of antecedent knowledge and of hypothesis have no clear line of demarcation, for the practical discrimination of knowledge and hypotheses, however sharply they may be divided in thought, is beset with insuperable difficulties.

If "This classification of considerations controlling the organization of research is . . . comprehensive, and applicable to any other systematic research" it should be applicable to our investigation which appears to be systematic research (or closely analogous to research) as judged by these same considerations.

RESTATEMENT OF OBJECTIVES

In the first place, we recognize that our work is directed toward the major objective of maintaining the nation's oil reserve. Our part as petroleum geologists is to find more oil, and we have oriented our current research-committee program toward that purpose. Two steps are recognized in our two stated objectives and it might not be amiss to repeat these here.

First—To make a reconnaissance review of research in petroleum geology and allied sciences with specific reference to exploration

Second—To formulate a comprehensive research program, which the Association might adopt as its recommendation for that research which is most needed to improve our ability to find oil—and I might add—to formulate a program that will work.

GENERAL ORGANIZATION OF SURVEY (TABLE II)

The first step with respect to the survey of research was to review the activities of previous research committees in discussions with the previous chairman, M. G. Cheney, supplemented by reading the annual reports of all previous research committees of the Association. Activities of the American Petroleum Institute committee which formulated Project 43 were discussed with G. C. Gester. Several committee reports of the Division of Geology and Geography of the National Research Council also gave valuable assistance in the development of our preliminary ideas. This was, and still is being, accompanied by formulation and rejection of hypotheses as additional considerations were brought to bear from the fields of limitations and analogy.

Preliminary discussions occupied two months during which we discussed different forms of organization of the committee which varied from four subcommittees to fifteen; from a total membership of 24 to one of 100; and from three to seven agenda.

The limiting conditions are time, mores, men, and money—principally mental mores. The habit of thinking in terms of a few projects and limited areas had to be discarded in favor of a survey of a whole field of exploration activities.

In selecting the principal methods of investigation, we adopted, as working hypotheses, three points of view from which to make a survey of research: by subjects, by objectives and by areas. Of these three, the first is closer to fundamentals, that is to say, general relationships. Therefore, the five subcommittees were organized to summarize what is known, what is being done and what needs to be known with respect to our objectives in the fields of stratigraphy and sedimentation, tectonics, reservoir fluids, geophysics and geochemistry, and borderland fields of production engineering.

The second survey, based on objectives, can be treated from the point of view of planning and selection of method, with emphasis on the need for additional methods, techniques, or interpretations to be used in looking for new provinces, trends or localized prospects.

SURVEY OF RESEARCH NEEDS OF DIFFERENT REGIONS

The third point of view is based on a consideration of research needs in different geological regions, and here we need the help of the twenty-six affiliated geological societies and other groups of geologists in the United States and abroad. The subcommittee on Project Areas will correlate the projects and ideas submitted from the different areas and will attempt to formulate an interregional concept of our most urgent research needs.

There are so many causal interrelationships between sedimentation and tectonics and their combined effect on reservoir fluids that it is desirable that all three should be taken into consideration in the formulation of regional research projects although emphasis tends to place each problem in (1) stratigraphy, (2) structure, or (3) reservoir fluids, as a general classification.

Examples are selected from the Gulf Coast.

Stratigraphic example.—The Recent of the Gulf of Mexico and adjacent continental areas of deposition compared with the Tertiary of the Gulf Coast. Studies in synecology, its processes and sedimentary products; bacteriology, physics, and chemistry of diagenesis; regional and detailed morphology of sedimented area and source area, in relation to contemporaneous structure and the effect on sedimentation; organic content of sediments to determine areas of greatest concentration and their relationship to sedimentary environments; comparison with known conditions in the Tertiary. Further investigation of the Tertiary.

Structural examples.—A. Salt domes; accurate correlation of strata involved in folding; detailed mapping of the geometry of the structure; test for recent movement; scale-model experiments of salt-dome formation; geothermal studies; analysis of formation water; mapping of flow structure in salt mines. B. Homoclinal tectonics, regional strike fault systems, their relationship to "flexures." C. Wedges of sediment along line of maximum change in rate of gulfward thickening, lines of isopachal thicks and thins; relationship to old continental shelves or slopes; relationship to sand distribution; effect on distribution of reservoir fluids.

These structural systems appear to be the result, to a large extent, of "endogenetic" forces produced by sedimentary processes within the basin. Their resolution would contribute largely to an understanding of the mechanics of deformation of basins of the Gulf of Mexico type.

Reservoir-fluid example.—Stratigraphic and geographic distribution of Gulf Coast oil fields; the areal distribution of production within many sand groups is distributed in belts, roughly paralleling strike; biofacies and lithofacies relationships of such belts; their effect on distribution of reservoir fluids; area and closure of structure compared with estimated total recovery; formation water content, updip and downdip and within producing belts.

These examples are taken from the Gulf Coast because of my more recent familiarity with that area. They are selected to illustrate the presence of stratigraphic, structural, and reservoir-fluid elements in most regional problems. The interaction of sedimentation and tectonics and their combined effect on the distribution of reservoir fluids has not been pointed out in each example for lack of space, but will be readily apparent to those geologists who are familiar with these problems.

The cooperation of affiliated societies and other groups of geologists is essential to a comprehensive list of regional problems and a recognition of correlatable elements which may serve as multiple points of attack on basic problems. Similarly, we must rely on those who are most intimately familiar with these regional problems to produce formulations (outlines) which will contain all of the important elements. The work of the subcommittee on Project Areas will be greatly facilitated if these projects are broken down as precisely as conditions permit.

Preliminary lists, to be submitted by January 15, have been requested from several societies. These will be duplicated by mimeographing and will be distributed to all affiliated societies and to other groups who request them. They will also be distributed to the members of the research committee and consultants. The January 15 progress reports of the subcommittee will be given similar distribution.^{12a}

This interchange of ideas should assist in making more complete revised lists and revised formulations of projects. All lists of projects should be in our hands by March 15 to give us time to formulate an over-all program before the annual meeting in Chicago on April 1.

FORMULATION OF PROGRAM

The completed work of the three surveys, made from the point of view of subjects, objectives, and areas, will form the greater part of the antecedent knowledge which we need to know and to classify in order to proceed toward our second objective which is the formulation of a program. We also need to know how many thousand research agencies there are throughout the country and we need to form some idea of their relative functions in the field of research as they affect petroleum geology.

There are said to be 4,000 consultants and industrial laboratories listed in a compendium that will be issued by National Research Council this spring. I do not know how many hundred universities and colleges may be doing research or what part of this may be of interest to us. The subcommittee on Research Facilities is conducting this part of the investigation.

When we consider the breakdown of our program we should know something about the research functions, from our point of view, of the Federal surveys, the State surveys, the National Research Council, endowed research institutions (Mellon and Carnegie), the Geological Society of America, universities, the American Petroleum Institute, oil-company research laboratories, study groups of geological societies affiliated with the Association, and individual researches.

We should form an idea of the need for industry-wide cooperative research in exploration. It is necessary here to consider not only the petroleum industry itself, but other possible sources of energy as balanced against other possible national needs before such sources can be developed.

Our program should also be conditioned by the obstacles to such an industry-wide program, and also by analogy to similar programs in other industries, and by programs of research institutes, such as Carnegie, Mellon, Batelle, Southern, and Armour.

Some of the most serious obstacles to cooperative research are to be found in the consideration that those companies which wish to support research work five to ten years ahead of the drill are already doing so in their own laboratories, or may be planning to do so in the near future, while those companies which do not wish to work more than four years ahead of drilling operations could not be expected to be enthusiastic about long-range cooperative research.

Where then is the basis for the expectation that a cooperative research program, however well formulated, would receive adequate support from industry? It is this. War research has shown us that multiple, cooperative attack on some problems of applied research telescopes the time factor—thus making it possible to bring 32 years of research within the eight- or possibly within the four-year line.

Another form of research which would appear to fall within the cooperative field is that which deals with problems of such wide scope that their solution could hardly be expected to offer advantage to any one company.

^{12a} This distribution has already been made and copies are available for others who request them.

These two categories seem to offer plenty of room for a cooperative program of fundamental, long-range research of wide scope.

When and if we have been able to make such a program, I believe that the research committee should recommend that the program be submitted to a committee composed of those Association members who are most closely in touch with management and the research needs of individual companies. These men possess the sources of information, the experience, and the point of view which would make it possible to carry through the feasible portions of the program to the operating stage.

CONCLUSIONS

In closing, I wish to make an appeal to you for your help. There is a great deal of work to be done. But action is not enough and we will surely fail of our objective if, in our sense of urgency and desire to get past the "talky-talk" stage, we reach a conclusion before it is justified and waste our opportunity on a mess of pottage. Somewhere in the maze of scientific knowledge, there exists a "best" program and it is our job to find the approximation of that ideal.

By "we," I mean the research men—in other words the entire A.A.P.G., for it is generally recognized that there is a research quality in all geologic work. Barton¹⁴ discussed this extensively in "The State of Geologic Research in the Oil Industry" and listed nearly all types of routine geologic work as "research in the line or routine work." Barton points out that the research character of this work is readily apparent if we compare it with much academic research.

Who then will do all this work? The A.A.P.G. could hire one or ten men to make our program but, if this were done, the rest of us would relax until the program was presented and then tear it apart. We could hire a firm of research consultants for twenty-five or fifty thousand dollars to make the survey for us and admit by implication our incapacity to do the job ourselves. Even then we would practically have to do the work over if we wanted to check the report adequately.

It is my belief that there is no substitute for voluntary committee work and that the work and the thinking that are needed to construct our research program must be done by the Association and by such non-members as are willing to give us their help as consultants on our several subcommittees.

But the research committee can act only as the spearhead of research thinking for the Association. Without a shaft, the spearhead goes nowhere and unless the shaft is heavy and the thrust is strong, it will not penetrate to the heart of a problem that is as tough as this one promises to be. The membership of the Association surely carries plenty of weight and the urgency of our needs supplies the force that is required to drive the blow home.

Progress reports of research-committee activities will be prepared from time to time and will be mimeographed for distribution to those who are interested. We will also mimeograph some general articles on research such as those by G. K. Gilbert, Henry Shaler-Williams, and F. W. Clarke. These also will be made available to those who want them.

If you will send your names to vice-chairman E. Robert Atwill (Pacific Coast), Winthrop P. Haynes (Atlantic Coast), or myself (Mid-Century-Gulf Coast), we will send copies of them to you.

I hope that you will discuss our current research program and that you will send us the results of those discussions. It is obvious that more good ideas will come from the membership at large than can be produced by a committee of 26 men—no matter how hard they work. With your interest and active help I believe that we will accomplish our objectives.

¹⁴ *Op. cit.*

DISCUSSION

ROWELL WELL NO. 1, HEIDELBERG FIELD, MISSISSIPPI¹

LLOYD W. STEPHENSON²

Washington, D. C.

Reference is made to the paper entitled "Significance of Upper Cretaceous Fossils from Wells in Mississippi."³ In Figure 2, pp. 1012-1013, the difference in elevation above sea-level of the *Ostrea oleana* zone in the Gulf Refining Company's Rowell well No. 1 and in the Gulf Refining Company's Lewis Morrison well No. 1 (nearly 900 feet) was correctly assumed to be due to a fault displacement between the two wells, but the writer did not know at the time that this fault intercepted the Rowell well somewhere below the *Ostrea sannionis*⁴ bed (depth, 5,547-5,572 feet), cutting out an important part of the section. The *O. sannionis* bed is believed to mark the approximate base of beds of Austin age.

Several very poorly preserved ammonite prints were found in a core sample of dark shale from the Rowell well at depths between 5,752 and 5,872 feet and were questionably referred to the genus *Prionotropis*. In the outcrop in Texas the range of this ammonite is restricted to a relatively narrow zone in the upper part (but not the uppermost part) of the Eagle Ford shale. Had the identification been correct the age indicated would have been upper Eagle Ford. Unaware at the time that the section had been shortened by faulting, and finding the prints of ammonites resembling *Prionotropis* at what appeared to be about the right stratigraphic position below the *Ostrea sannionis* bed, the writer's correlation of the containing dark shale with the Eagle Ford seemed reasonable; the correlation should, of course, have been questioned.

As shown in Figure 2 of the paper cited, an undescribed species of the small bivalve genus *Uddenia* was identified in both the Rowell and the Helen Morrison wells, in the former about 300 feet below the *Ostrea sannionis* zone, and in the latter about 1,000 feet below that zone. The apparent discrepancy in the stratigraphic position of *Uddenia* in the two wells was recognized but was assumed to be due to its having a rather long vertical range. Actually, in view of the shortened section, *Uddenia* in the Rowell well is nearly at the right level to correspond with its position in the Helen Morrison well.

The species of *Uddenia*, being new, is in itself of no value in making a long-distance correlation, and it was not the intention to give the impression that it indicated Eagle Ford age. The correlation of this zone with the Eagle Ford was based on the supposed presence of *Prionotropis* in the zone in the Rowell well, a supposition now admitted to have been erroneous. The writer now considers this zone to lie somewhere within the age limits of the Tuscaloosa formation (Lewisville age).

¹ Manuscript received, December 21, 1945. Published by permission of the director of the Geological Survey.

² Principal geologist, Geological Survey, United States Department of the Interior.

³ Lloyd W. Stephenson, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 7 (July, 1945), pp. 1008-18.

⁴ Incorrectly called *Ostrea alifera* Cragin (variety) in *Jour. Paleon.*, Vol. 19, No. 1 (1945), p. 72.

EAST TEXAS GEOLOGICAL SOCIETY FIELD TRIP,
DECEMBER 1 AND 2, 1945¹

C. L. MOODY²
Shreveport, Louisiana

A well planned and highly satisfactorily conducted field excursion resulted from the labors of the 1945 field trip committee of the East Texas Geological Society. That committee, consisting of A. C. Wright, T. H. Shelby, J. T. Rouse, and C. I. Alexander (chairman), chose for its theme a meritorious paper by Rouse, published in the April, 1944, *Bulletin*, entitled "Correlation of the Pecan Gap, Wolfe City, and Annona Formations in East Texas." All the significant outcrops described in that paper were made part of the field trip agenda and despite somewhat inclement weather, all were visited by the 50 or more enthusiastic field trippers who registered for the event. The evidence upon which Rouse had based his published conclusions was reviewed at each stop by word of mouth as well as by printed statement in the well ordered guidebook especially prepared for the field excursion.

As was to be anticipated, the conclusions arrived at by Rouse and supported by the field trip committee were not negated by the field party's examination of the outcrops visited. In Rouse's publication it was shown that the Pecan Gap formation, essentially a chalk, unconformably overlies the Wolfe City formation and that it thins from 120 feet in Hunt County to zero feet in Red River County. It was furthermore shown that the Wolfe City formation, largely clastic in its type locality in Hunt County, has been traced eastwardly into Red River County where, by a gradual decrease in sand content it merges into the Annona chalk of the type locality. Most of these conclusions had been proclaimed in previous publications by earlier workers.³ One new concept was developed, however. It was discovered through a study of surface materials and of subsurface samples obtained in an exploratory core-drilling campaign conducted by the Magnolia Petroleum Company in western Red River County that the Pecan Gap chalk is locally absent, the upper Taylor marl (Marlbrook?) lying directly on the Wolfe City formation in a small area. As this takes place where the Wolfe City is seen to be rapidly merging into the Annona chalk it would seem to follow that the type Annona is all older than the Pecan Gap chalk. Previous to the publication of the results of this study it had been thought that the upper part of the Annona chalk was the exact equivalent of the type Pecan Gap chalk. A final determination of equivalences awaits a more accurate designation of a type locality for

¹ Manuscript received, January 10, 1946.

² The Ohio Oil Company.

- ³ (a) 1918. L. W. Stephenson, "A Contribution to the Geology of Northeastern Texas and Southern Oklahoma," *U. S. Geol. Survey Prof. Paper 120*, pp. 129-53.
- (b) 1925. A. C. Ellis, "The Age and Correlation of the Chalk at White Cliffs, Arkansas, with Notes on the Subsurface Correlations of Northeast Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 8, pp. 1152-64.
- (c) 1927. L. W. Stephenson, "Notes on the Stratigraphy of the Upper Cretaceous Formation of Texas and Arkansas," *ibid.*, Vol. 11, No. 1, pp. 1-19.
- (d) 1928. C. H. Dane and L. W. Stephenson, "Notes on the Taylor and Navarro Formations in East Central Texas," *ibid.*, Vol. 12, No. 1, pp. 41-59.
- (e) 1929. C. H. Dane, "Upper Cretaceous Formations of Southwestern Arkansas," *Arkansas Geol. Survey Bull.* 1.
- (f) 1934. A. C. Ellis and John Teagle, "Correlation of Pecan Gap Chalk in Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 11, pp. 1506-36.
- (g) 1937. *Geologic Map of Texas*; N. H. Darton, L. W. Stephenson, Julia Gardner; U. S. Geol. Survey.
- (h) 1937. L. W. Stephenson, "Stratigraphic Relations of the Austin, Taylor and Equivalent Formations in Texas," *U. S. Geol. Survey Prof. Paper 186*, pp. 133-46.

the Annona chalk. This observer is of the opinion that the matter is of sufficient importance to Cretaceous stratigraphers to justify another field conference for the purpose of arriving at agreement as to what shall be called the type section of the Annona chalk. With this matter finally determined most of the present vagueness in Taylor nomenclature as applied to northeast Texas and adjacent parts of Arkansas and Louisiana would automatically clear up. Rouse's paper, Alexander's researches, and the 1945 field trip of the East Texas Geological Society have contributed in no small way toward the final achievement of this desirable end.

The road log of the field trip is printed in the East Texas Geological Society's booklet describing the trip. It contains much good geological information. Copies of the guidebook (22 pp., with map and road log) may be purchased at \$2.00 per copy, by writing T. H. Shelby, secretary-treasurer, Humble Oil and Refining Company, Tyler, Texas.

FOR AVAILABLE GEOLOGISTS

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

STRATIGRAPHY AND OIL-PRODUCING ZONES OF THE PRE-SAN ANDRES FORMATIONS OF SOUTHEASTERN NEW MEXICO, BY ROBERT E. KING

REVIEW BY E. RUSSELL LLOYD¹
Midland, Texas

"Stratigraphy and Oil-Producing Zones of the Pre-San Andres Formations of Southeastern New Mexico," by Robert E. King, with Explanatory Note by Robert L. Bates. *State Bureau of Mines and Mineral Resources Bull. 23* (Socorro, New Mexico, 1945). 34 pp., 3 pls. Price, \$0.50.

Drilling of deep tests in southeastern New Mexico and West Texas in the past few years has added immeasurably to knowledge of lower Permian and pre-Permian stratigraphy and has resulted in the finding of new and important oil fields and new zones of production. King has presented a very concise and timely discussion of the pre-San Andres stratigraphy and development in southeastern New Mexico. The Bulletin is labeled "A Preliminary Report" inasmuch as it is anticipated that further drilling will bring out data which may materially modify the conclusions reached from present available data. Three plates of cross sections form an integral and valuable part of the report. On these, detailed sample logs are reproduced on a vertical scale of 500 feet to the inch. It has long been the contention of the reviewer that cross sections do not prove anything but merely serve to illustrate the conclusions of the author. King's sections appear to be very convincing in themselves but, of course, will have to stand the test of time. Correlations of upper Permian as well as pre-San Andres formations are shown.

Correlations are made in so far as possible with the well known Permian formations which crop out in central New Mexico. The difficulties in carrying the formational boundaries into the predominantly limestone section of southern Lea County are pointed out, particularly the boundaries of the Yeso and Abo formations. On the other hand, some sandy zones have been found useful in subsurface correlations but have not been traced to the surface outcrops. One of these, the Drinkard sandy member of the Yeso formation, has been given formal description.

King's suggestion of a possible correlation of the Abo formation with the lower part of the Clear Fork of central Texas will not be generally accepted, at least without more data than are now available. One objection to this correlation is that the Clear Fork on the outcrop is about 1,100 feet thick and King's suggested correlation would make it equivalent to more than 3,000 feet of Yeso and Abo beds.

King includes in the Hueco formation all Permian beds below the Abo shale but suspects that some of these beds may be Leonard in age. The reviewer, with others, would prefer to restrict the Hueco by definition to beds of Wolfcamp age but believes it improbable that any beds of Leonard age have been included in the Hueco in New Mexico.

The sketchy character of our knowledge of the Pennsylvanian of southeastern New Mexico is well shown by King's cross section and discussion. All series of the Pennsylvanian except the Morrow are represented but in the present state of knowledge it would be difficult to predict the areal distribution of any one series.

The important sequence of subsurface rocks which for the present can be classified

¹ Review received, December 13, 1945.

only as Devonian (?) and/or Silurian have been studied in detail by a number of company geologists because they contain important oil reservoirs. They are not as yet productive in southeastern New Mexico but their potential importance justifies King's careful analysis of possible correlations.

Probably because of an error in drafting, the sequence from Devonian to Ellenberger is shown on Plate 1 as offlapping the pre-Cambrian on the flank of a structural high instead of being truncated at the base of the Permian.

King's treatment of controversial questions is clear and unprejudiced. His own interpretations are presented but not in a dogmatic way. The reviewer hopes that his suggestions with regard to nomenclature will be generally accepted.

THE PULSE OF THE EARTH, BY J. H. F. UMBGROVE

REVIEW BY W. A. VER WIEBE¹
Wichita, Kansas

The Pulse of the Earth, by J. H. F. Umbgrove. Publisher, Martinus Nijhoff, The Hague, Netherlands (1942). 179 pp., 94 figs., 6 large pls., and 2 tables, with an appendix of explanatory notes.

Dr. Umbgrove is professor of geology at the University in Delft, Holland. The chapters in the book under review are adapted from lectures which the author delivered during the years 1939 to 1941 before the Geophysical Section of the Geological and Mining Society for the Netherlands and Its Colonies; the Geological Society of Leyden; and the Diligentia Society at the Hague. The material in the book is so arranged that it leads up naturally to a chronological relation of periodic events in the earth. The author shows that the first stage is characterized by a worldwide regression of the epi-continental seas, resulting probably from the simultaneous but opposed movements of both the continents and the ocean floors. During the period of intensive erosion which ensues, the climatological zones show a greater differentiation than had been previously the case. Compression of the crust and folding the layers in the geosynclines takes place with the somewhat later intrusion of acid batholiths.

The second stage is marked by decreasing crustal compression, the emergence of high mountain chains, and the formation of new geosynclines and basins. During the third stage the mountains reach their full height. Dome-shaped elevations and the formation of rift valleys characteristic of post-orogenic time also characterize this stage. Finally, volcanism and the outpouring of basic lavas complete the high-lights of this phase. The interesting table on page 63 shows that this sequence of events has taken place twice since Cambrian time. The first climactic peak was reached in Carboniferous time and the second one in Tertiary time. Each was marked by widespread mountain building and great differentiation of climatic zones ending in an ice age. Both present an average cadence of 50 million years and a periodicity of approximately 250 million years. This may be called the cosmic cycle. It is closed by the events of two post-climactic stages. For, during the fourth stage in earth history the mountains are eroded and the ocean level rises to encroach on the continents as epi-continental seas. During the fifth stage the vast epi-continental seas reach maximum extent while the climate becomes mild and equable over large portions of the globe.

The foregoing summary is an over-simplification of conclusions reached by the author in the first eight chapters of the book. Admittedly, the fundamental causes of these

¹ University of Wichita, Wichita, Kansas. Manuscript received, December 24, 1945.

events and relations between them are very abstruse and deep-seated. Therefore the reader will find that the painstaking presentation of data and arguments contained in the eight chapters are by no means easy reading. The author clearly indicates that he has thoroughly exhausted the researches of such men as Vening Meinesz, Barrell, Bucher, Daly, Griggs, Holmes, Wegener, Joly, DuToit, Stille, Suess, and Cloos, to mention only the leading philosophers of earth structure and history. For that reason this book will probably find its greatest usefulness in helping the reader to find and evaluate the ideas and concepts presented by the men mentioned. Dr. Umbgrove has dug out and polished up many gems of geologic thought which might otherwise lie unnoticed and unappreciated in obscure or forgotten journal pages. The following list of topics treated will convey some idea of the immensity of the scope of the fundamental researches covered. In Chapter I, entitled, Space and Time, the topics treated comprise (among others) the age of the earth, the internal constitution of the earth, and the history of the earth's crust. In the second chapter, entitled Mountain Chains, the grouping of the mountains and the centrifugal migration are especially well treated. The sial and the sima are exhaustively analyzed in the next chapter, as is also the nature of tectonic and magmatic cycles. The oscillation of sea-level, the topography of ocean floors, continental drift, the permanence of continents, and related topics are treated in chapters five and six. Climatic variations, ice ages, and periodic differentiation of flora are discussed in the next two chapters. Much essential material is presented in small type in the appendix which accompanies the very valuable plates (of the world) showing Caledonian, Variscian, Laramide, and Alpine mountains. Plate V (in colors) shows the chronological development of the continents. Plate VI shows the great basins of the world classified with regard to age relation to the great orogenic epochs.

A SURVEY OF WEATHERING PROCESSES AND PRODUCTS,
BY PARRY REICHE

REVIEW BY RONALD K. DEFORD¹
Midland, Texas

"A Survey of Weathering Processes and Products," by Parry Reiche. *University of New Mexico Publications in Geology No. 1*. 87 pp., 6 figs. Paper, octavo. Albuquerque, New Mexico (1945). Price, \$0.75.

Number one of a new series of University of New Mexico Publications in Geology sets a high standard. It is a brief review of modern concepts of weathering.

Weathering is the response of materials which were in equilibrium within the lithosphere to conditions at or near its contact with the atmosphere, the hydrosphere and perhaps still more importantly, the biosphere.

Are not geologists apt to be so preoccupied with deformation, glaciation, and the work of wind and water, that they greatly underestimate the biosphere as a geologic agent? Weathering disperses the elements of original rocks and concentrates them in different places on the globe. As they pile up there, does not the whole process tend to run down? The answer is no, largely because of the continued addition of solar energy by means of living beings and life processes. By the way, petroleum, a product of the biosphere, is made and destroyed in or near the zone of weathering.

Potassium and sodium each make up $2\frac{1}{2}$ to 3 per cent of the average composition of igneous rock, but potassium is notoriously incompetent to reach the sea. It gets a slow start because potash feldspars are relatively more resistant to weathering than soda feld-

¹ Argo Oil Corporation. Review received, January 9, 1946.

spars. Then plants consume potassium avidly and, using it over and over again, prevent its escape from the zone of weathering. "The often-cited adsorptive affinity of clay for potash is apparently a minor factor."

"Most geologists would profit by an acquaintance with soils, however slight." Reiche's 23 pages of "Soil-forming Processes and Soils" could serve as an introduction. It is a geologic prejudice, still widely held, that the composition of a soil is determined primarily by the parent material. About 75 years ago

Russian scientists noted that identical source materials under the broad plains of Russia gave rise to very different soils, according to the climate of the locality. . . . In the Ukraine the top of a ruined fortification made of Silurian limestone slabs has developed an approximately normal soil profile at the rate of 12 inches in 230 years.

Again the point is that soil formation appears to depend less on the lithosphere than on the biosphere; consequently, "climate, relief and time determine soil character and parent material is of minor importance," although its influence is noticeable in arid regions, at least.

Caliche, a striking feature of our country's southwestern face, is claimed by the soil scientists as their own. Whether geologists can or can not grant that even the thick massive caliches are soil-formed, it is incumbent upon them thoroughly to understand the pedologist's concept of calcification.

Laterites and lateritic soils result from tropical weathering, but no agreement has been reached as to the details of the process. "When incorporated in the geologic record they are evidence of unconformities and if widespread, of peneplanation." Other antique soils mark breaks in the geologic record and bear witness to the ancient climates that produced them.

Reiche² has endeavored to devise a graphic

method of indicating the state and stage of a specimen as a whole relative to its course of alteration and of expressing the distance it has yet to go to attain to probable end-products (Figure 4, page 50).

Of the physical processes of weathering, all secondary in importance, only unloading and crystal growth (including frost action) are considered significant. Thermal expansion and contraction, time-honored in geological classrooms, are negligible.

Colloids take part in many ways. Colloid plucking, as yet not investigated, may be added to the physical processes. A large part of chemical weathering is a study in colloid chemistry. Among acids as weathering agents, H_2CO_3 is preëminent and acid clay colloids are suspected to rank second in effectiveness.

Stratigraphers, note well: Quartz grains and other weather-resistant mineral grains may be rather well rounded and surprisingly well size-sorted before undergoing any transportation.

This publication, full of physical, chemical, geologic, geomorphic, and pedologic terms, needs an index. Also, it would seem proper for the University of New Mexico to encourage its wider distribution by lowering the price.

² Parry Reiche, "Graphic Representation of Chemical Weathering," *Jour. Sed. Petrology*, Vol. 13, No. 2 (August, 1943), pp. 58-68.

SELECTED WELL LOGS OF COLORADO, BY CLARK F. BARB

"Selected Well Logs of Colorado," by Clark F. Barb. *Quarterly Colorado School of Mines*, Vol. 41, No. 1 (Golden, January, 1946). 436 pp., 6 figs., 1 folded chart, 1 folded map. Department of Publications, Colorado School of Mines, Golden. Price, \$2.00, postpaid.

Volume 41, Number 1, the January, 1946, issue of the *Quarterly* of the Colorado School of Mines, contains "Selected Well Logs of Colorado," by Clark F. Barb, head of the department of petroleum engineering at the School of Mines. This number was prepared under the Colorado Industrial Development Research. It is a compilation of significant well logs from all parts of Colorado.

The logs selected are from more than 6,000 well logs in the library of the School of Mines. In addition, scores of logs have been obtained from other sources: the United States Geological Survey, oil companies, drillers, and other industries. The group of logs has been edited to select those logs giving valuable information on geology and petroleum possibilities. About 500 detailed logs and about the same number of summarized logs have been selected from virtually every county in the state. Included in the introductory material are generalized structural sections across the Green River Basin, the North Park Basin, the Denver Basin, and the Uinta Basin, a geological correlation chart, a new field correlation chart and an accompanying two-page inserted index map.

On a large map of Colorado, in the envelope on the back cover, are plotted the location of many wildcat wells and the general outline of the producing fields. Where the information was available the surface elevation, the total depth, and the lowest formation encountered are plotted for each test well. This map is complete to the end of 1944, insofar as records are known. Each detailed log in the text is numbered, and a corresponding number is shown on the map beside the more important or deep tests.

CAMBRIAN HISTORY OF THE GRAND CANYON REGION, BY EDWIN D. MCKEE AND CHARLES E. RESSER

"Cambrian History of the Grand Canyon Region," by Edwin D. McKee and Charles E. E. Resser. *Carnegie Institution of Washington Pub.* 563 (Washington, D. C., 1945). 232 pp., 12 figs., 27 pls. 6.75×9.75 inches. Price: paper cover, \$2.50; cloth binding, \$3.00 postpaid.

The Cambrian deposits of Grand Canyon include numerous widespread fossil beds, thin but persistent conglomerate zones, and horizons of distinctive lithology that serve as reliable key beds, thus making possible the tracing of various rock units along the excellent and practically continuous exposures of the canyon walls. With this approach, a detailed study has been made of the relation of time planes to lithogenetic units and of the association and sequence of facies within definite time zones. Results are supplemented by data obtained through a comprehensive review of the fauna made by Charles E. Resser and presented as Part II of this publication.

Time planes which cut diagonally across lithogenetic units give a measure of the rate of transgression and regression. Other evidence indicates that the Cambrian sea advanced by a series of rapid and extensive movements, after each of which it remained relatively stable and accumulated uniform sediments for a long period. After some of the advances there were times of temporary retreat, which also were relatively rapid and were followed by extended periods of uniform environment. During each transgression essentially the same sequence of facies was developed from the open sea to the shore, but during times of regression a different sequence resulted. Furthermore, certain lithologic types were developed only during periods of transgression, others only during regressive stages.

Periods of widespread advance by the Cambrian sea are believed to have been inaugurated by rapid sinking of the basin; those of regression by slower sinking or cessation. During regressions, deposits built up to or near the base level of deposition, causing detrital sediments to advance seaward.

RECENT PUBLICATIONS

ARIZONA

*"Cambrian History of the Grand Canyon Region," by Edwin D. McKee and Charles E. Resser. *Carnegie Inst. Washington Pub.* 563 (Washington, D. C., 1945). 232 pp., 12 figs., 27 pls. Approx. 6.75×9.75 inches. Price: paper cover, \$2.50; cloth binding, \$3.00, postpaid.

ARKANSAS

*"Age Relations of Stanley and Jackford Formations of Oklahoma and Arkansas," by Chalmer L. Cooper. *Jour. Geol.*, Vol. 53, No. 6 (Chicago, November, 1945), pp. 390-97; 2 tables.

BOLIVIA

*"Bolivia's Oil Situation," by J. Elmer Thomas. *Oil Weekly*, Vol. 120, No. 6 (Houston, January 7, 1946), International Section, pp. 45, 46, 50; 5 photographs, 1 map.

CHILE

*"Chile's 'Farthest South' Exploration," by J. Elmer Thomas. *Oil Weekly*, Vol. 120, No. 6 (Houston, January 7, 1946), International Section, pp. 24-28; 4 photographs, 2 maps, 2 tables, 1 chart.

COLORADO

*"Selected Well Logs of Colorado," by Clark F. Barb. *Quar. Colorado School of Mines*, Vol. 41, No. 1 (Golden, January, 1946). 436 pp., 6 figs., 1 chart, 1 folded map of the state. Department of Publications, Colorado School of Mines, Golden. Price, \$2.00, postpaid.

ECUADOR

*"Exploration in Eastern Ecuador," by J. Elmer Thomas. *Oil Weekly*, Vol. 120, No. 6 (January 7, 1946), International Section, pp. 41-43; 2 photographs, 1 map.

ENGLAND

*"The Oil Fields of England," by J. Brian Eby. *Oil Weekly*, Vol. 120, No. 6 (Houston, January 7, 1946), International Section, pp. 3-16; 8 tables, 5 photographs, 5 figs.

EUROPE

*"An Oil Man in Europe," by J. Brian Eby. *Oil Weekly*, Vol. 120, No. 6 (Houston, January 7, 1946), International Section, pp. 18-23; 5 photographs.

GENERAL

"Press Releases, Preliminary Maps, and Preliminary Reports Released by the Geologic Branch and Alaskan Branch between January 1, 1938, and January 1, 1945," by Lois S. Kent and R. P. Keroher. *U. S. Geol. Survey* (December, 1945). Pamphlet containing complete list of preliminary reports and maps dealing with mineral deposits, chiefly in the United States and Alaska. It does not include the Survey publications announced by the regularly printed "Publications of the Geological Survey." Obtainable by addressing the Director, Geological Survey, Washington 25, D. C.

The Mines Magazine, 10th annual petroleum number (1945), Frank C. Bowman, edi-

tor. Approx. 118 pp., illus. Published by Colorado School of Mines Alumni Association, 734 Cooper Building, Denver, Colorado. Price, \$1.00. Includes, among others, the following articles.

"The Rangely Oil and Gas Field and Uinta Basin," by Bernard M. Bench.

"Limestones Formed by Foraminifera," by J. Harlan Johnson.

"Sketch of Oil Developments in Alberta, Canada," by L. W. Storm.

"The Panhandle Oil and Gas Field," by E. G. Dahlgren.

"The Origin of Hydrocarbons in the Uinta Basin," by Clark F. Barb.

**Petroleum Register*, 24th edition (1945-1946). 600 pp. The yearly directory and register of the active oil companies of the world. Published by Mona Palmer, 2 West 45th Street, New York 19, N. Y. Page, 8.5 × 11.25 inches. Cloth cover, 9 × 11.625 inches. Price, \$10.00, net.

*"Abstracts and Index (July-December)." *Bull. Geol. Soc. America*, Vol. 56, No. 12, Pt. 2 (New York, December, 1945), pp. 1143-1225. Abstracts of papers delivered orally or by titles before the December, 1945, meetings of the Mineralogical Society of America, the Society of Economic Geologists, the Paleontological Society, the Society of Vertebrate Paleontologists, and the Geological Society of America, held at Pittsburgh, Pennsylvania.

**Our Oil Resources*, edited by Leonard M. Fanning. 331 pp. Eighteen outstanding authorities and oil-company executives have contributed to this symposium. "An accounting of our oil resources is given not alone in terms of geological knowledge but also in terms of human resources—engineering and scientific learning and application, and private initiative and incentive which are the real keys to our future oil discoveries."—From the *Editor's Preface*. Includes: "The Earth's Petroleum Resources," by Wallace E. Pratt (originally in *The Journal of Business*); "Estimate of United States Oil Reserves," by the American Petroleum Institute; and "Our Reserves of Coal and Shale," by K. C. Heald and Eugene Ayres (originally in pamphlet form). Published by McGraw-Hill Book Company, Inc., New York (1945). Cloth, 5.5 × 8.5 inches. Price, \$4.00.

*"Bibliography of Seismology No. 16, Items 5788-5893, July to December, 1944," by Ernest A. Hodgson. *Pub. Dominion Observatory*, Vol. XIII (Dept. Mines and Resources, Ottawa, Canada, 1945), pp. 269-284. Price, \$0.25.

**Ibid.*, "No. 17, Items 5894-5934, January to June 1945," pp. 285-93. Price, \$0.25.

KANSAS

*"Exploration for Oil and Gas in Western Kansas during 1944," by Walter A. Ver Wiebe. *Kansas Geol. Survey Bull.* 56 (Lawrence, November, 1945). 112 pp., 30 figs., 35 tables.

MEXICO

*"Mollusca of the Tertiary Formations of Northeastern Mexico," by Julia Gardner. *Geol. Soc. America Mem.* 11 (New York, December 15, 1945). 332 pp., 23 pls., 1 fig., 6 tables. Approx. 6.25 × 9.75 inches. Cloth.

MISSISSIPPI

**Geologic Map of Mississippi*, prepared by the Mississippi Geological Society with the cooperation of the Geological Survey of the United States Department of the Interior. Compiled by W. E. Belt, H. R. Berquist, G. F. Brown, L. C. Conant, D. H. Eargle, U. B. Hughes, F. S. MacNeil, W. H. Monroe, J. H. Morris, J. H. Stillwell, and H. A. Tourtelot, from data submitted by oil companies active in Mississippi, from published reports of the Mississippi State Geological Survey, and from field revisions. Sheet, 35.5 by 47 inches. Surface geology in colors. Scale 1:500,000. Approximately 1.25 inches equal 10 miles. Published by the Mississippi Geological Society (1945). Orders may be sent to J. B. Wheeler, secretary-treasurer, care of Stanolind Oil and Gas Company, Jackson, Mississippi. Price, \$3.25, postpaid.

**Fifth Field Trip of the Mississippi Geological Society, December 7-8, 1945: Eutaw-Tuscaloosa* [Guide book]. 23 pp. of text, including road logs. Description of stratigraphy by D. Hoye Eargle, Louis C. Conant, and Watson H. Monroe, published by permission of the director of the United States Geological Survey. 8 profiles, maps, and correlation charts. Four U.S.G.S. maps folded in pocket: Tuscaloosa, Cottondale, and Eutaw Quadrangle topographic sheets and *Preliminary Map 37*, Oil and Gas Ser., "Geological Map of Tuscaloosa and Cottondale Quadrangle, Showing Areal Geology and Structure of Upper Cretaceous Formations." 8.5×11 inches. Spiral plastic binder. Orders may be sent to J. B. Wheeler, secretary-treasurer, care of Stanolind Oil and Gas Company, Jackson, Mississippi. Price, \$3.50, postpaid.

MONTANA

"Graphic Sections of Mesozoic and Paleozoic Rocks That Underlie the Basin Areas in South-central Montana," by H. D. Hadley, L. S. Gardner, and C. P. Rogers, Jr. *U. S. Geol. Survey Prelim. Chart 19*, Oil and Gas Investig. Ser. (December, 1945). Sheet, 44×65 inches. 4 lines of graphic sections on vertical scale of 1 inch equals 120 feet. Index map and descriptive text. For sale by Director, Geological Survey, Washington 25, D. C.; Billings, Montana; Tulsa, Oklahoma; Denver, Colorado; Casper, Wyoming. Price, \$0.40.

"Maps Showing Thickness and General Distribution of Mesozoic and Paleozoic Rocks in South-Central Montana," by C. P. Rogers, Jr., L. S. Gardner, and H. D. Hadley. *U. S. Geol. Survey Prelim. Map 43*, Oil and Gas Investig. Ser. (December, 1945). Single sheet containing series of 5 maps and north-south geologic section. For sale as foregoing. Price, \$0.40.

NEW JERSEY

*"Revision of the Upper Cambrian Faunas of New Jersey," by B. F. Howell. *Geol. Soc. America Mem. 12* (New York, November 12, 1945). 46 pp., 8 pls.

NEW MEXICO

"Engineering Report on the Grayburg Cooperative and Unit Area, Eddy County, New Mexico." *U. S. Geol. Survey*. Informal oil-field report. 12 pp. text and 10 maps and charts. Copies may be obtained free of charge, upon request, from Oil and Gas Supervisor, Geological Survey, Federal Building, Roswell, New Mexico.

OKLAHOMA

*"The West Edmond Oil Field of Oklahoma," by E. G. Dahlgren and Dan O. Howard. *Mining and Metallurgy*, Vol. 26, No. 468 (New York, December, 1945), pp. 607-10; 1 sketch map.

*"Age Relations of Stanley and Jackfork Formations of Oklahoma and Arkansas," by Chalmer L. Cooper, *Jour. Geol.*, Vol. 53, No. 6 (Chicago, November, 1945), pp. 390-97; 2 tables.

OREGON

"Geology of Northwest Oregon West of Willamette River and North of Latitude 45° 15'." *U. S. Geol. Survey Prelim. Map 42*, Oil and Gas Investig. Ser. (Washington, D. C., December, 1945). Sheet, 44×64 inches. Map scale, 1 inch equals 2.3 miles. Contains text, 2 structure sections, 6 stratigraphic sections. May be purchased from Director, Geological Survey, Washington 25, D. C.; Room 234 Federal Building, Tulsa, Oklahoma; Room 533 U. S. Post Office and Courthouse Building, Los Angeles, California; and Room 314 Boston Building, Denver, Colorado. Price, \$0.70.

PENNSYLVANIA

*"The Pittsburgh-Pottsville Boundary," by George H. Ashley. *Jour. Geol.*, Vol. 53, No. 6 (Chicago, November, 1945), pp. 374-89; 8 figs.

ROCKY MOUNTAINS

*"The Oil and Gas Record within the Rocky Mountains," by Thomas S. Harrison. *Oil Reporter*, Vol. 2, No. 21 (Denver, December 25, 1945), pp. 3, 22. 1st instalment of address given at the annual meeting of the Rocky Mountain Oil and Gas Association at Casper, Wyoming, December 7 and 8.

VENEZUELA

*"Bibliographia e Indice de la Geologia de Venezuela," by H. D. Hedberg and F. Hedberg. *Ministerio de Fomento Servicio Tecnico de Minería y Geología*. From *Revista de Fomento*, Vol. 7, Nos. 58-59 (Caracas, 1945). 50 pp.; folded index map of geologic-geographic provinces of Venezuela. Scale, 1.25 inches equals approximately 100 miles. 7-page introduction in Spanish.

WISCONSIN

*"Sediments of Trout Lake, Wisconsin," by W. H. Twenhofel, W. E. McKelvey, H. F. Nelson, and D. E. Feray. *Bull. Geol. Soc. America*, Vol. 56, No. 12, Pt. 1 (New York, December, 1945), pp. 1099-1142; 3 pls.

WYOMING

"Geologic and Structure Map of the Little Buffalo Basin Oil and Gas Field and Vicinity, Park and Hot Springs Counties, Wyoming," by T. F. Stipp and Harvey F. French. *U. S. Geol. Survey* (December, 1945). Scale, 2 inches equals 1 mile. 100-foot structure contours. 2 structure sections, 1 columnar section. For sale by Director, Geological Survey, Washington 25, D. C.; 314 Boston Building, Denver, Colorado; 305 Federal Building, Billings, Montana. Price, \$0.15.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Paleontology* (Tulsa, Oklahoma), Vol. 20, No. 1 (January, 1946).

"Some Jurassic and Cretaceous Corals from Northern Mexico," by John W. Wells.

"Allegheny Fossil Invertebrates from Eastern Ohio—Nautiloidea," by Myron T. Sturgeon.

"A Study of Two Arcid Pelecypod Species from Western South America," by Don L. Frizzell.

"Fresh-Water Mollusks from the Morrison Formation (Jurassic) of Sublette County, Wyoming," by Teng-Chien Yen and John B. Reeside, Jr.

"*Stichocassidulina*, a New Genus of Foraminifera from Northwestern Peru," by Benton Stone.

"A New Crocodilian from the Eocene of Utah," by Charles W. Gilmore.

"*Pulpia*, a New Upper Cretaceous Bivalve Mollusk from Texas and Maryland," by Lloyd W. Stephenson.

"New Names for Homonym Species of Cambrian Hyolithidae," by B. F. Howell.

"Notes on the Nomenclature of *Hyolithes*," by G. Winston Sinclair.

"Permian (?) Bryozoa from Sustut Lake, British Columbia," by Madeleine A. Fritz.

"*A Rhopalonaria* in the Dundas Formation at Toronto," by Madeleine A. Fritz.

"*Hyolithes Cooperi*, New Name," by J. Stewart Williams.

"Corrections to 'New Upper Cambrian Trilobites from the Lévis Conglomerate,'" by Franco Rasetti.

**Journal of Sedimentary Petrology* (Tulsa, Oklahoma), Vol. 15, No. 3 (December, 1945)

"Sedimentary Variation: Some New Facts and Theories," by Percival Allen.

"Transportation of Marine Beach Sand by Flotation," by K. O. Emery.

"Phosphate Deposit near Princetown, Victoria, Australia," by George Baker.

"Bottom Sediments of Green Lake, Wisconsin," by W. H. Twenhofel and Dan E. Feray.

THE ASSOCIATION ROUND TABLE

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JOINT ANNUAL MEETING, STEVENS HOTEL, CHICAGO, APRIL 1-4, 1946

The Stevens Hotel is the convention headquarters for the annual meeting of the Association, April 2-4, 1946. Also, the Society of Exploration Geophysicists meets on April 1-2, and the Society of Economic Paleontologists and Mineralogists meets on April 3-4.

Hotel room reservations should be made now. Available space is limited, but it is reasonably certain that sufficient hotel space will be available for all desiring to attend the meeting, including the wives. Make your own reservations with the Stevens Hotel. After the Stevens is full, the Stevens will refer your request to other hotels who have agreed to cooperate. You will receive your letter of confirmation from the hotel accepting the reservation. If you prefer some particular hotel, try to make your reservation directly with that hotel. The Stevens will not accept reservations for blocks of rooms. You are encouraged to arrive Sunday, March 31, because congestion in the hotels on Mondays and Tuesdays results in some confusion in reservations.

The executive committee is arranging the convention. It is the general committee and the program committee. The absence of space prohibits commercial and educational exhibits. There will be no golf tournament. The only official entertainment is the dinner-dance. Weather permitting, a field trip to points of local interest will probably be sponsored by the Illinois Geological Society, Friday, April 5. The sessions are tentatively arranged according to the following plan.

THE ASSOCIATION ROUND TABLE

- April 1 (Monday). S.E.G. sessions.
A.A.P.G. committees and research conferences.
Annual meeting business committee.
Night. Review and discussion, research program.
- April 2 (Tuesday). Joint sessions A.A.P.G., S.E.P.M., S.E.G.
Presidential addresses.
Nomination of officers.
Papers on Application of Geology to Military Science.
Special papers.
S.E.G. sessions (afternoon).
Night. Address by Eugene Holman.
- April 3 (Wednesday). Tectonics and oil-field papers.
S.E.P.M. sessions.
Balloting for officers.
Dinner-dance.
- April 4 (Thursday). Trends and Developments since 1941.
Regional and oil-field papers.
S.E.P.M. sessions.
3:30 P.M. Special meeting to consider amending Certificate of Incorporation.
3:40 P.M. Annual business meeting and announcement of election of officers.

Conferences will be held on subjects such as "Training in Geology," "Rock Color Chart," "Development of Plans and Financing of Recommended Research Projects." The detailed printed program will be ready for distribution at the convention.

VETERANS' RETRAINING PROGRAM IN GEOLOGY¹

W. H. BRADLEY²
Washington, D.C.

During the past five years it is estimated that the armed forces absorbed fifteen hundred young American geologists of graduate, near-graduate, or post-graduate status, only a small number of whom had gained any experience in professional application of their learning.

During their terms in the armed services few of these young men have had the opportunity of using their geological training or of acquiring additional geologic knowledge. It may therefore be assumed that they have suffered considerable loss of geologic skill and knowledge and are thus not prepared to resume their studies or professional activities in competition with those geologists whose careers have not been interrupted by the war.

Because of this situation and the current demand for trained geologists, the U. S. Geological Survey proposes to undertake a program of training in the form of supervised field,

¹ Published by permission of the director of the Geological Survey. Manuscript received, January 12, 1946.

² Chief geologist, Geological Survey, United States Department of the Interior.

laboratory, and office work that will enable discharged veterans to adjust themselves more quickly and with more confidence in resuming their careers. The Survey proposes to undertake only this applied phase of the retraining. It recognizes that many of the expected trainees will require preliminary academic courses in college or university geology departments that are equipped to give concentrated courses of graduate calibre.

The proposed dual program has been discussed with heads of the geology departments of the Universities of Chicago, Columbia, Harvard, Johns Hopkins, Princeton, and Yale; and they have indicated their approval of the plan in principle. Heads of geology departments in other schools interested in participating in this phase of the program may obtain pertinent information from the heads of the geology departments of those universities. Further information concerning the Geological Survey's phase of the program may be obtained by writing to W. H. Bradley, Chief Geologist, Geological Survey, Washington 25, D. C.

The instruction of qualified veterans in participating schools will, insofar as is feasible, be adjusted to the specific needs and interests of the individual to equip him better to undertake and benefit by Survey or other professional experience in field, laboratory, and office work during the 1946 field season.

Candidates for these temporary appointments to the Geological Survey will be selected on a competitive basis through the channels of the Civil Service Commission, and in accord with veterans' preference policies. It is hoped, however, that veterans who apply will have had the benefit of the preparatory college or university retraining before they seek appointment.

The number of veterans which the Survey will be able to absorb will depend on the amount of funds appropriated to the Survey for geologic investigations. An estimate of the size of the field program should be available by spring after the House reports out the appropriation bill. As many as possible of the most competent temporary appointees will be given the opportunity of accepting more permanent appointments on the Geological Survey staff, or will be given aid in obtaining appointments in other governmental agencies or in industry.

This dual program will operate on a very flexible basis, to take care of all individual cases, involving individuals whose academic training and professional experience to date lie within a rather wide range. It will be fitted also to individual desires, to allow for academic training only, for Survey experience only, or for both, depending on the qualifications and wishes of the individual.

MEMORIAL

ALEXANDER WATTS MCCOY (1889-1944)

Alexander Watts McCoy, past president of the American Association of Petroleum Geologists, and known over the world as a leader of progressive thought among petroleum geologists, died on June 30, 1944, as the result of an attack of virus pneumonia. He is survived by his second wife, Elizabeth Shapard Terry McCoy, of Tulsa, Oklahoma, two sons and a daughter by a former marriage, Alexander Watts McCoy III, Thomas McCoy, and Mrs. James Bumpass, a brother, John Porter McCoy, and a sister, Miss Louise McCoy. His death is mourned by his devoted family and by hundreds of firm friends all over the world. To many of these his untimely passing was a very personal tragedy.

Alex McCoy came of pioneer stock. His grandfather, for whom he was named, had sailed around the Horn, had joined the '49ers, and had settled at last in the vast new empire of the Middle West to carve roads out of the wilderness and to establish a home at a place in Missouri fittingly called Independence.

It was here, two generations later on February 6, 1889, that Alex McCoy was born, son of Lewis Foulke McCoy and Elizabeth Johnson McCoy; and it was here in the wholesome atmosphere of the small Missouri River town that he grew to manhood. Wise parents saw to it that Alex with his brother and two sisters mixed work with play, and as a result the children grew up sturdy and self-reliant. Even as a boy, Alex was an expert swimmer and an experienced hunter, but his interest in nature went deeper than that. His inquisitive and retentive mind reached out to learn the birds, the trees and the rocks of his small world . . . a world which was to widen far beyond his wildest boyhood dreams, and which was to yield up many of its deepest secrets to this same brilliant and original mind.

It is evident that from his early youth he possessed many of the characteristics of his grandfather. By birth, by tradition, Alex McCoy had entered into the heritage of the pioneers, those . . .

Big-hearted, big-handed lords of the axe, the plow and the rifle,
Tan-faced tamers of horses and lands, themselves remaining tameless.

It was this pioneering spirit, this active, independent and questing soul, together with the highest qualities of character and intellect that Alex McCoy brought to the science to which he dedicated his life.

He did not, however, determine upon his life work until his senior year in college. When he entered the University of Missouri in 1906, it was with the determination of following in his grandfather's footsteps and becoming a civil engineer. With characteristic enthusiasm he plunged into campus life: the Engineering School, football, basket ball, tennis, and track. A popular member of the Delta Tau Delta Fraternity, he invariably enlivened its "swab sessions" by his wit, and endeared himself to all by his spirit of friendly helpfulness.

In 1910, however, he enrolled in a course in geology taught by E. B. Branson. The new subject caught his imagination almost immediately. Here was a new world, its horizons almost unguessed, its frontiers practically uncrossed. From that time on Alex McCoy's life took on new purpose and meaning. As long as he lived, the lure of unblazed trails across the vast, unknown continents of geological possibilities challenged him; and his answers to those challenges made his name famous and his memory blessed.



ALEXANDER WATTS MCCOY



After he received his degree in Civil Engineering he stayed on at the University of Missouri to do graduate work in geology, serving first as a student assistant and then as an instructor. His thesis on the artesian waters of part of Missouri, later published as an Engineering Experiment Station Bulletin of the University, earned for him his Master's Degree in geology in 1914. He then accepted an appointment at the University of Oklahoma where he taught physiography, mineralogy, economic geology, and map interpretation. During this time he wrote his now famous paper on "Some Effects of Capillarity on Oil Accumulation," published in the *Journal of Geology*, Vol. 24 (1916) and in Vol. 1 (1917) of the *Bulletin of the Southwestern Association of Petroleum Geologists*.

It was at this time, too, that he gave the first public demonstration of the originality of thought that was to characterize his geological study throughout his life. At a meeting of geologists in 1914 he displayed an apparatus which he designed and built to show how oil migrated into anticlines by the pressure of ground water. The display attracted much comment and led to offers from several oil companies, one of which he accepted.

Alex McCoy's first venture in the oil business, however, was of very short duration. Hired by E. DeGolyer to go to Mexico for the Mexican Eagle Oil Company, he arrived to find a revolution in progress. He did not find this situation to his liking and remained on the job only a few days. He next took a position with the Marland Oil Company, doing surface mapping in the Osage hills. These were the days when transportation from one camp site to another was dependent upon teams and wagons secured from scattered ranchers.

In the spring of 1917, McCoy became chief of the subsurface division for the Empire Gas and Fuel Company. With tremendous holdings around the newly discovered Augusta and Eldorado oil fields acquired as the result of surface geological work started in 1913, the Empire Company showed great enthusiasm for geology and geologists. When McCoy joined the organization its geological department had 250 members, including 100 geologists scattered over the Mid-Continent. One of the great advances brought about by the company was the establishment of a separate department for subsurface study, and it was to head this new department that Alexander W. McCoy joined the Empire. Seldom, if ever, had such an opportunity for exploration and research been offered, and McCoy promptly launched a broad, comprehensive program of subsurface investigation.

Methods developed under his direction have had a profound influence on the subsurface techniques in use to-day. At an early date he recognized the fact that subsurface data would greatly implement studies of paleogeography and stratigraphy. He pioneered in oil-field water sampling, studies of oil-producing sands, studies of water encroachment, subsurface mapping, sample logging, the use of the centrifuge for separation of oil from bottom sediment and water, and in studies of the subsurface distribution of rocks and the determination of old shore lines. He was also a leader in the development of such techniques as the use of three-dimensional peg models, and he conducted numerous experiments to study and illustrate the accumulation and migration of oil in anticlines. He also experimented on volume changes and the development of pressure by capillary relationships. Further experiments demonstrated the importance of faulting and showed that faulting had produced oil reservoirs under conditions where accumulation would not otherwise have taken place. Maps were drafted under his supervision which showed the direction and length of all known faults in Oklahoma. All this early work of Alex constitutes a thrilling chapter in the history of oil exploration and production, and its importance can hardly be overestimated.

While he was chief research geologist for the Empire Gas and Fuel Company, the influence of his personality and character upon his young associates was tremendous, and he early demonstrated his unusual ability in training and inspiring the men who worked

for him. By precept and example he imbued them with his own passion for analytical thinking, intellectual honesty, scientific insight, insistence on accuracy and detail in gathering facts, and imagination in their interpretation. In this way, perhaps more than in any other, he influenced the progress of petroleum geology. Many of his "students" trained in his methods have attained high position in the oil industry and have perpetuated and advanced both his techniques and his scientific philosophies. Associated with him, or coming under his influence, was a great school of young men ambitious to accomplish and appreciative of the opportunities offered by Alex's leadership. For many of them, this was the beginning of a life-long and deeply cherished friendship.

McCoy's enthusiasm for geologic research caused him to visit many universities, and his discussion of the problems of the petroleum geologist brought about several helpful changes in college curricula.

From the spring of 1920 until the spring of 1924 he operated as a consulting geologist, first with the firm of McCoy, Shidel and Pasewalk, with offices in Bartlesville, and later with another firm under the name of Alex W. McCoy and Company. Both of these ventures prospered in a modest way though the abrupt drop in the price of oil caused rough going for enterprises of this kind.

During the spring of 1924 Alex McCoy moved to Denver, Colorado, as vice-president in charge of land and geology for the newly organized Marland of Colorado. Characteristically, his department again became a comprehensive school of geology and research. Again, a new group of men came under the McCoy influence, were inspired by his enthusiasm and trained in his methods. Much scientific information and a number of formal papers of major importance to economic geologists were partial results of this company-sponsored research.

The family life of Alexander Watts McCoy was a happy one, and the pleasant relationships maintained between Alex and his family and his many friends was one of the characteristics for which he was admired by all who knew him. Shortly before he joined the staff of Empire, Alex, on April 17, 1917, married his college sweetheart, Helen Aylesbury of St. Louis, Missouri. Three children were born to them, Alexander, Jr., Phyllis, and Thomas. Helen McCoy was a talented, friendly woman, an accomplished pianist and a trained singer. She was noted as a gracious hostess, and the McCoys are remembered by their friends for delightful parties, musical evenings, and picnics in the Colorado mountains. The family were actively affiliated with the Episcopal Church, and for a time in Ponca City, Alex served as Sunday School superintendent in the Grace Episcopal Church.

A few months after his term as president of the American Association of Petroleum Geologists, on September 6, 1927, Helen McCoy died. She had been a true helpmate, a devoted mother, and a sympathetic companion. Her passing was a devastating blow to her husband.

The void in McCoy's life left by the death of his wife was partly filled by his mother-in-law, Mrs. Gertrude Aylesbury. This splendid lady became a member of his family and assumed the unfinished work of rearing the McCoy children. Affectionately known to family and friends alike as "Mamma Gertie," Mrs. Aylesbury won the admiration of all who knew her.

In November, 1943, Alex McCoy married Mrs. Elizabeth Shapard Terry of Tulsa. Their friendship dated back to college days. The children of each had married and moved away, and the last year of McCoy's life was greatly enriched by their happy companionship.

After retrenchments by Marland had all but eliminated the Colorado organization, McCoy became vice-president in charge of land and geology for the Marland Production Company which was a merger of Marland of Colorado, Marland of Texas, and Marland

of Oklahoma. In May, 1928, he established his family in Ponca City, Oklahoma, where he served with the Marland Production Company until he resigned early in 1929 to become vice-president of the newly organized E. W. Marland Company, Inc. which "went down" with the crash in 1929.

He ran into rough going during the lean years of the early thirties, but accepted the vicissitudes of life uncomplainingly and patiently worked to rebuild his world. At the time of his death McCoy was vice-president in charge of the land and exploration departments of the Deep Rock Oil Corporation which he had joined as manager in October, 1940. Of this phase of his life one has written: "It is my belief that it can be safely said that McCoy made more discoveries in the brief time he was with Deep Rock than he ever before had to his credit."

In addition, he showed exceptional capacity as an executive. Even for a man of McCoy's ability this is an achievement worth noting. He had made his early reputation as one of the more scientific of our petroleum geologists. Now in his last years he was to make an outstanding, though all too brief, success as an oil executive. There is no question but that these last years were the most productive of his life. He was at the peak of his achievement when he was stricken with his fatal illness.

Throughout his long career Alexander W. McCoy was active in the American Association of Petroleum Geologists, and eight of his papers appear in the publications of the Association. On Marh 27, 1926, at Dallas, McCoy who had served as vice-president of the Association in 1920, was elected president. During his term of office two important projects were completed: the selection of Tulsa as the permanent headquarters of the Association, and the appointment of Mr. J. P. D. Hull, formerly chief geologist of the Louisiana Oil Refining Corporation, as business manager. Following his term of office as president, McCoy's interest in the Association continued active. In 1928 he became chairman of the research committee, an office which he held ably until 1932. With Sidney Powers he actively collaborated in the planning, soliciting and editing of manuscripts for the symposium volumes, *Structure of Typical American Oil Fields*, and the sequel volume, *Problems of Petroleum Geology*.

Much of Alexander McCoy's thinking was termed unorthodox, and some of his controversial opinions were the cause of numerous discussions which clarified thought on many abstract principles and theories. In connection with McCoy's unorthodox thinking, one who knew him well has written the following brief eulogy.

A gentler soul never graced our profession, but no one ever put a saddle on his mind. Many called him wild; I called him free. He was not vicious, he was honest; he was not clever, he was intelligent; he was not contentious, he was curious; he did not contribute any ponderous tomes to the bookshelves of geologic libraries; it was his abiding belief that the state of our geologic knowledge was insufficient to justify committing conclusions thereon to print. Some thought him iconoclast, but to me he was the antithesis of that. He always maintained that there was nothing mysterious about geology, but rather that our uncertainties arose out of our insufficient facts. He tackled all of life with zest, and, being in some measure unorthodox, he had his critics. Often his friends did not feel at liberty to go as far afield in either their investigations or their theorizing as did Alex, but they admired him and loved him. If every geologist could throw off classical inhibitions and tackle the problems of the art or the science, whichever it should be called, with the same joyous abandon that Alex McCoy brought to his task, mountains would indeed be moved, and the secrets of the deep be brought to light.

In 1929 McCoy became a member of the American Association for the Advancement of Science, and a Fellow in 1931. He was also A.A.P.G. representative on the Division of Geology and Geography of the National Research Council from 1928 to 1931.

A memorial to so rich and significant a life can but touch upon its salient features. Alex McCoy's work is done. His ashes—in accordance with his own request—were scattered from an airplane over the Osage County hills where he did his early work. His spirit

MEMORIAL

nevertheless lives on in the enthusiasm and love of geology with which he endowed all who worked with him, and in ideas and techniques which he bequeathed to the geological world.

... He held his place—
Held the long purpose like a growing tree—
Held on through blame and faltered not at praise,
And when he fell in whirlwind, he went down
As when a kingly cedar green with boughs
Goes down with a great shout upon the hills
And leaves a lonesome place against the sky.

THE AMERICAN ASSOCIATION
OF PETROLEUM GEOLOGISTS

THE EXECUTIVE COMMITTEE

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

Lieutenant Commander ROBERT C. LAFFERTY, geologist, 4007 Staunton Avenue, Charleston, West Virginia, is on terminal leave after spending more than 2 years as Navigational Officer and Flight Navigator with Naval Air Transport Squadron Five, flying the Aleutian Islands, Alaska, and into Siberia, U.S.S.R. The petroleum project at Point Barrow, Alaska, was serviced by his squadron.

HUGH O'KEEFE, recently with the Phillips Petroleum Company, Bartlesville, is now in charge of the geological and land departments of the Davon Oil Company, Oklahoma City.

J. BRIAN EBY, consulting geologist and geophysicist of Houston, Texas, has been travelling in Europe reporting on conditions in the oil industry. He has several articles in the *Oil Weekly*. In the issue of January 7, he has a page of "Personal Notes from Europe."

WALTER KAUNHOWEN, geologist with the Deutsche-Vacuum Oil A.G., at Hamburg, Germany, is reported to have been killed while examining oil properties in Poland during the war.

MAX K. H. BAUERMANN is acting chief geologist for the De Bataafsche Petr. Mij., 30 Carel van Bylandtlaan, The Hague, Netherlands. The Royal Dutch Shell offices in the Hague are undamaged by the war.

J. A. A. MEKEL, formerly chief geologist of the Shell and professor of geology at Delft University, Holland, was executed by the Germans in The Hague, June, 1941, accused of "underground activity."

BRYAN D. BECK, JR., employed by the Sun Oil Company, Beaumont division, as a petroleum geologist and engineer, for the past 6 years, has become associated with Randolph C. Reed in the leasing and royalty and consulting geology business. The business address is the Reed Company, Fannin and Main Streets, Beaumont, Texas.

MAX BORNHAUSER, of the Continental Oil Company, Lafayette, Louisiana, spoke on "Marine Sedimentary Cycles of the Tertiary in the Mississippi Embayment," at the regular monthly meeting of the New Orleans Geological Society, January 7.

EDWARD D. LYNTON, research geologist for the Standard Oil Company of California, has been granted a leave of absence by that company and will leave soon for Paris, France. He will be in the employ of the French Government and will be in charge of Rehabilitation of the French Petroleum Industry. Among other duties, he will direct exploration work in southern France, with headquarters at Paris.

EVERETT C. EDWARDS has resigned his position in the geological department of the General Petroleum Corporation in Los Angeles to go to Bogota, Colombia, where he will be a geologist for the Atlantic Refining Company.

PETER H. GARDETT, recently Lieutenant (j.g.) in photo interpretation for the U. S. Navy, has returned to work for the General Petroleum Corporation. He will be located in Los Angeles.

CHARLES W. LANE has resigned from the Pure Oil Company to accept a position as geologist with Deep Rock Oil Corporation, Tulsa, Oklahoma.

ROSS A. MAXWELL, superintendent of the Big Bend National Park, spoke before the West Texas Geological Society on December 17, 1945, on "The Geology of the Big Bend National Park Area." The lecture was illustrated with kodachrome slides and an outline of the proposed development of the Park area was given.

JOSEPH H. SHARPE, with the Frost Gravimetric Surveys, Inc., Tulsa, Oklahoma, spoke before the West Texas Geological Society on Friday, January 4, 1946. His subject was "The Necessity for Geologic Participation in the Prosecution of Geophysical Exploration."

CHESTER A. BAIRD, of Canal Winchester, Ohio, has returned to Venezuela, after a year or more in the United States. He has been appointed resident manager in Caracas, in charge of the activities of the Venezuelan Atlantic Refining Company. He has had many years of varied experience in Venezuela, chiefly with Gulf Oil Corporation subsidiaries.

CHARLES A. STEEN, of Houston, Texas, has returned after 2 years of exploratory work in the Amazon Basin for the Socony-Vacuum Oil Company in Peru. He is now doing graduate work in geology at the University of Chicago.

HERBERT V. LEE, of Ithaca, New York, has returned after serving as Captain with the 459th Bomb Group (14). He is with The Texas Company at Corpus Christi, Texas.

EDWARD L. MOORE has been in Ecuador with the Anglo-Ecuadorian Oil Fields, Ltd., since 1937, and as chief geologist since 1941. He is returning to his home address, c/o Nicholls, "The Villa," Probus, Cornwall, England.

H. L. TIPSWORD, who has been in Bogota, Colombia, for the Socony-Vacuum Oil Company, C.A., has changed his address to 230 East Seminole Place, Tulsa, Oklahoma.

CORNELIUS SCHNURR has finished his work with the Petroleum Administration for War at Houston. He may be addressed at 3816 Hazard Street, Houston, Texas.

CLARK T. SNIDER has resigned his position with the Globe Oil and Refining Company and has opened his office as consulting geologist at 4519 East English, Wichita, Kansas.

ERIC H. JAGER, of Wichita, Kansas, has accepted a position in the geological department of the Stanolind Oil and Gas Company, Tulsa, Oklahoma.

CHARLES M. REED, of Rochester, New York, is with the American Republics Corporation, Houston, Texas.

D. A. PROBST has changed his address from Pittsburgh, Pennsylvania, to Mene Grande Oil Company, Apartado 45, Barcelona, Venezuela.

GEORGE C. HARDIN, JR., has left the Carter-Gragg Oil Company, where he was geologist and exploration superintendent, to join the staff of M. T. HALBOUTY, consulting geologist and petroleum engineer, with offices in the Shell Building, Houston, Texas.

A. B. MCCOLLUM is associated with the Southern Minerals Corporation of Corpus Christi, Texas, as exploration geologist. He was formerly geophysical director for the Deep Rock Oil Corporation, Tulsa, Oklahoma.

J. C. SPROULE, division geologist, Saskatchewan, for Imperial Oil Limited, has been transferred to International Petroleum Company as assistant chief geologist with headquarters at 56 Church Street, Toronto, Ontario.

D. B. LAYER, formerly with McColl-Frontenac Oil Company, has resigned to accept a position with Imperial Oil exploration department, as assistant subsurface geologist, with headquarters at Calgary, Alberta.

J. D. WEIR, of the California Standard Company, discussed "Marine Jurassic Formations of Southern Alberta" at a regular meeting of the Alberta Society of Petroleum Geologists, held December 21, 1945, at the Palliser Hotel, Calgary. Weir's paper was correlated with W. A. COBBAN's recent publication "Marine Jurassic Formations at Sweetgrass Arch, Montana," appearing in the September *Bulletin*.

FRANK J. BELL, geologist, recently with the Carter Oil Company at Carmi, Illinois, is now doing independent work in the same area.

Newly elected officers of the Fort Worth Geological Society, Fort Worth, Texas, are as follows: President, JOHN H. WILSON, Independent Exploration Company; vice-president, EDWIN R. HOWSER, The Texas Company; secretary-treasurer, S. K. VAN STEENBERGH, Sinclair Prairie Oil Company.

MAX BORNHAUSER of the Continental Oil Company at Lafayette, Louisiana, presented his paper entitled "Marine Sedimentary Cycles of the Mississippi Embayment" at the meeting of the New Orleans Geological Society, January 9.

J. BRIAN EBY, of Houston, Texas, will serve as Graduate Professor of Geology under the Distinguished Lectureship arrangement at Agricultural and Mechanical College of Texas during the spring semester, 1946. Eby will give special courses in application of geology to petroleum production.

ROBERT H. DOTT, director of the Oklahoma State Geological Survey at Norman, Oklahoma, gave a lecture on "Survey Work and Program" before the Shawnee Geological Society at a meeting held on January 10 in the Aldridge Hotel.

On January 4, 1946, the West Texas Geological Society, Midland, Texas, in its annual meeting elected the following officers for the year 1946: president, B. A. RAY, consultant, Box 1385; vice-president, W. J. HILSEWECK, Gulf Oil Corporation; secretary-treasurer, CHARLES A. SHAW, Forest Oil Corporation, Box 366.

An unfortunate omission occurred in the announcement of the Distinguished Lecture Tour of CHESTER R. LONGWELL on page 1801 of the December *Bulletin*. The first sentence should have been: CHESTER R. LONGWELL, chairman of the department of geology at Yale University, discussed the little-understood structure *west* of the Colorado Plateau under the lecture subject, "Geology of the Basin Ranges: Revelations and Problems."

JOSEPH M. GORMAN, recently with the United States Geological Survey, is now with the Creole Petroleum Corporation of Maracaibo, Venezuela.

G. C. GUTSCHICK has resigned his position as geologist with the Magnolia Petroleum Company at Oklahoma City, Oklahoma, to accept a similar position with the Aluminum Ore Company, Rosiclare, Illinois.

The Rocky Mountain Association of Petroleum Geologists, Denver, Colorado, listened to B. M. BENCH on the subject, "Aviation Engineering in the CBI Theatre," on January 14.

R. B. DOWNING is division manager for the Lane-Wells Company at Oklahoma City.

CHARLES H. SUMMERSON, recently with the United States Geological Survey, has been appointed assistant professor in the Missouri School of Mines and Metallurgy, Rolla, Missouri.

Exploration in southern Chile under the direction of GLEN M. RUBY for the Chilean

Government has resulted in finding oil at the depth of 7410-7438 feet in the Spring Hill wildcat well near Punta Arenas, Tierra del Fuego. The United Geophysical Company, HERBERT HOOVER, JR., president, has conducted seismic surveys in the region for several years. Geological and geophysical personnel in the field includes: GLEN M. RUBY, LAWRENCE K. MORRIS, ROLLAND GILBERT, ANTHONY MALTOS, CLIFFORD L. MOHR, HEDWIG T. KNIKER, LELIO GORTON; and EDUARDO SIMIAN G. heads the local office of the Corporacion de Fomento de la Produccion de Chile.

RAYMOND C. ROBECK has left the United States Geological Survey. He is doing geological field work for The Texas Company in Oregon, with headquarters in Portland.

H. A. IRELAND, recently geologist with the United States Geological Survey at Norman, Oklahoma, has accepted appointment as head of the research laboratory of the Standard Oil Company of Texas, located at Midland, Texas.

EDWIN P. MATTHEWS has joined the staff of the Geotechnical Corporation of Dallas, Texas.

EDWARD LEE JOHNSON, consulting geologist of San Antonio, Texas, has returned after many months in service overseas. His first peace-time connection is with the Tripet Corporation, 630 Fifth Avenue, New York City. Johnson left on his assignment in Colombia, South America, early in January.

E. W. FOSSHAGE has been promoted to become chief geologist of the Shamrock Oil and Gas Corporation, Amarillo, Texas. He went with the company in July, 1944, after working for the Northern Ordnance Company at Billings, Montana.

HARRY M. BRITT, JR., has been employed as geologist with the Shamrock Oil and Gas Corporation. Britt has been in the Marine Corps $3\frac{1}{2}$ years.

Officers of the Geological Society of America are: president, NORMAN L. BOWEN, University of Chicago; vice-presidents, A. I. LEVORSEN, Stanford University, M. Y. WILLIAMS, University of British Columbia, CHESTER STOCK, California Institute of Technology, K. K. LANDES, University of Michigan; secretary, HENRY R. ALDRICH; treasurer, WILLIAM O. HOTCHKISS. The headquarters address of the Society is 419 West 117th Street, New York 27, N. Y.

RAYMOND SNYDER has been released from active duty as a major in the Air Corps and is employed as geologist by the Seaboard Oil Company, Jackson, Mississippi.

ALBERT WYNN has left the Kerlyn Oil Company to accept a position with the Mac-Millan Petroleum Company, El Dorado, Arkansas.

J. C. GILBERT, formerly with the Barnsdall Oil Company, is now with the Husky Refining Company, Cody, Wyoming.

THEODORE A. LINK has been appointed chief geologist for Imperial Oil Ltd., 56 Church Street, Toronto, Ontario. He has been associated with that company since 1919.

IAN CAMPBELL has returned to his position as associate professor of petrology and associate chairman of the Division of the Geological Sciences at the California Institute of Technology in Pasadena. During his leave of absence from the California Institute, Campbell served as a senior training engineer, and as chief of the editorial section, for the University of California Division of War Research, at the U. S. Navy Radio and Sound Laboratory in San Diego. For part of this period he also served as a BuShips Field Engineer-Instructor, and was attached to the Pacific Fleet Operational Training Command.

WILLIAM C. IKINS, formerly district geologist and recently research geologist, has resigned from the staff of the Tide Water Associated Oil Company. He will be associated with BASIL B. ZAVOICO, consulting geologist of 220 East 42d Street, New York City. Ikens will be in charge of the Houston office at 2012 Commerce Building which Zavoice is opening.

HAROLD SCOTT THOMAS, recently with the Petroleum Administration for War in Chicago, has been appointed professor of geology and geography at Roosevelt College, Chicago, Illinois.

GERALD C. ROBERTS has resigned from the American Trading and Production Corporation to become a consulting geologist at Midland, Texas.

D. C. OLSON is junior engineer for the Texas Railroad Commission at Midland, Texas.

E. RUSSELL LLOYD and JOHN M. HILLS have organized the Midland Sample Library, Midland, Texas, to classify and store oil-well samples by contract.

A. N. McDOWELL has been released from active duty in the Navy and is returning to the Creole Petroleum Corporation, Apartado 889, Caracas, Venezuela.

HAROLD KURTZ SHEARER, geologist for the Drilling and Exploration Company at Salvador, Bahia, Brazil, died of a heart attack at Salvador, January 18, at the age of 57 years. Shearer had a wide geologic and geographic experience in the Americas. Prior to his engagement with the Drilling and Exploration Company, he was with the Board of Economic Warfare stationed at Rio de Janeiro during 1943 and 1944. From 1919 to 1942 his home was in Shreveport, Louisiana. He was assistant State geologist of Georgia from 1914 to 1918.

DISTINGUISHED LECTURE TOUR

PARKE A. DICKEY, Quaker State Oil Refining Corporation, Bradford, Pennsylvania, appeared before twelve of the affiliated societies during the month of January, 1946, in a lecture tour under the auspices of the distinguished lecture committee. He discussed the "Geology and Secondary Recovery of Oil in the Pennsylvania and Eastern Oil Fields."

He addressed the following societies.

- January 4 Indiana-Kentucky Geological Society at Evansville
- 7 Mississippi Geological Society at Jackson
- 9 Shreveport Geological Society at Shreveport
- 11 South Louisiana Geological Society at Lake Charles
- 14 Houston Geological Society at Houston
- 16 Fort Worth Geological Society at Fort Worth
- 18 North Texas Geological Society at Wichita Falls
- 21 Dallas Geological Society at Dallas
- 23 East Texas Geological Society at Tyler
- 25 Oklahoma City Geological Society at Oklahoma City
- 28 Tulsa Geological Society at Tulsa
- 30 Kansas Geological Society at Wichita

HAROLD W. SCOTT, associate professor of geology, University of Illinois, Urbana, Illinois, discusses the "Upper Paleozoic History of the Rocky Mountains and Adjacent Great Plains" before a number of the affiliated societies between February 8 and March 4, 1946.

His itinerary follows.

- February 8 Alberta Society of Petroleum Geologists, Alberta, Canada
- 11 Wyoming Geological Society, Casper, Wyoming
- 12 Rocky Mountain Association of Petroleum Geologists, Denver, Colorado
- 14 Kansas Geological Society, Wichita

- 15 Oklahoma City Geological Society, Oklahoma City
- 18 Tulsa Geological Society, Tulsa, Oklahoma
- 19 Ardmore Geological Society, Ardmore, Oklahoma
- 20 North Texas Geological Society, Wichita Falls
- 21 Dallas Geological Society, Dallas, Texas
- 22 Fort Worth Geological Society, Fort Worth, Texas
- 25 West Texas Geological Society, Midland
- 27 Houston Geological Society, Houston
- March 1 Mississippi Geological Society, Jackson
- 4 Michigan Geological Society, Lansing

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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605 Union National Bank Building

Regular Meetings: 7:30 P.M., Geological Room,
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412 Union National Bank Building, and the Kan-
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Sohio Petroleum Corporation, Atlas Building

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Exhibit Building, Fair Grounds. Special meetings
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Lansing. Afternoon session at 3:00, informal din-
ner at 6:30 followed by discussions. (Dual meetings
for the duration.) Visiting geologists are welcome.

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OKLAHOMA	
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T E X A S

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Vice-President Edwin M. Rowser
The Texas Company, Box 1720
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Sinclair Prairie Oil Company
901 Fair Building

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

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Regular meeting held the second and fourth Mondays at noon (12 o'clock), Mezzanine floor, Texas State Hotel. For any particulars pertaining to the meetings write or call the secretary.

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Editor H. J. Simmons, Jr.
Godfrey L. Cabot, Inc., Box 1473

Meetings: Second Monday, each month, except June July, and August, at 6:30 P.M., Kanawha Hotel.

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Forest Oil Corporation, Box 366

Meetings will be announced.

W Y O M I N G

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P. O. Box 545

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Shell Oil Company, Inc.
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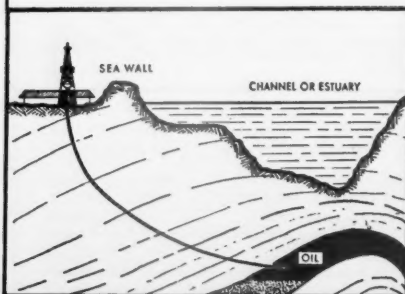
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BY

FRANK B. NOTESTEIN, CARL W. HUBMAN AND JAMES W. BOWLER

(PUBLISHED WITH THE PERMISSION OF THE COLOMBIAN PETROLEUM COMPANY)

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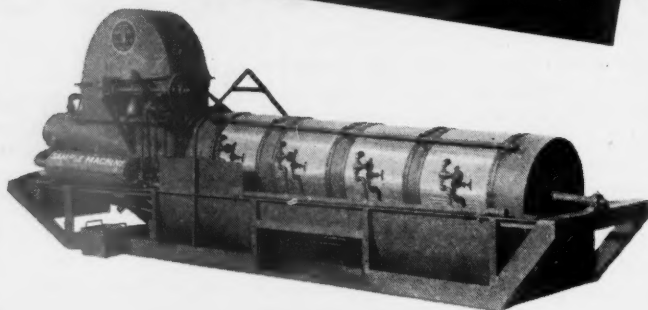
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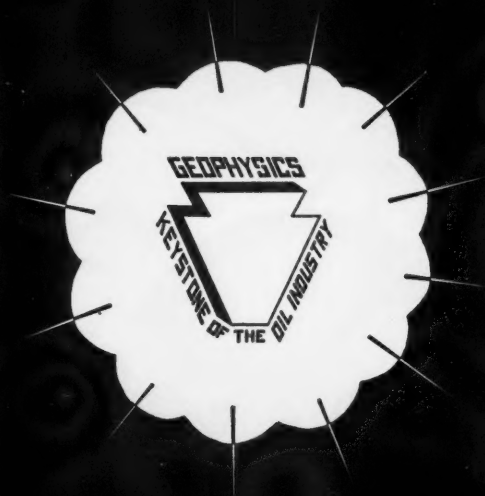
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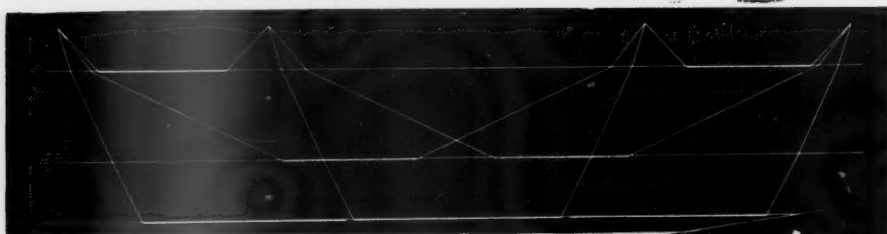
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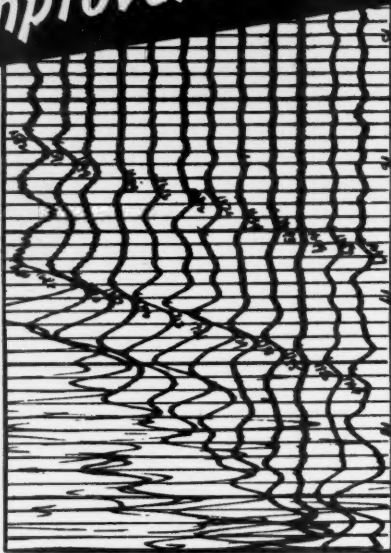
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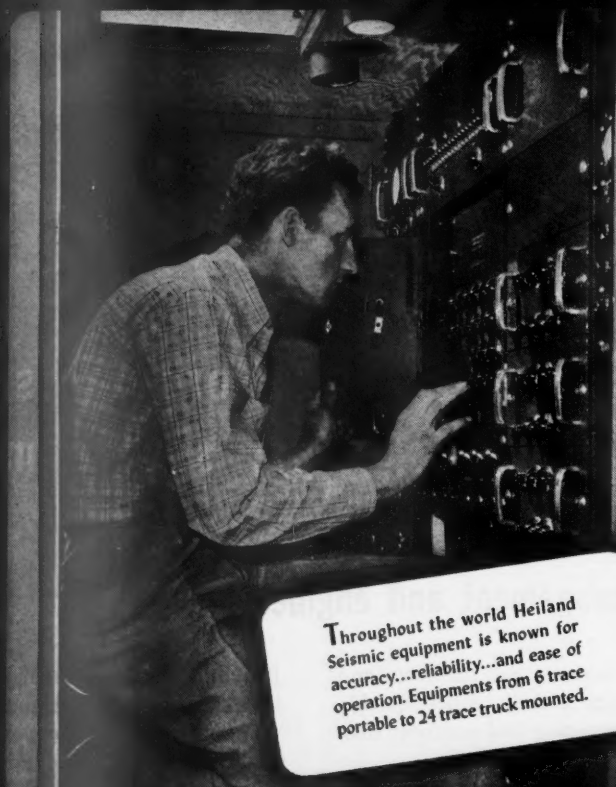
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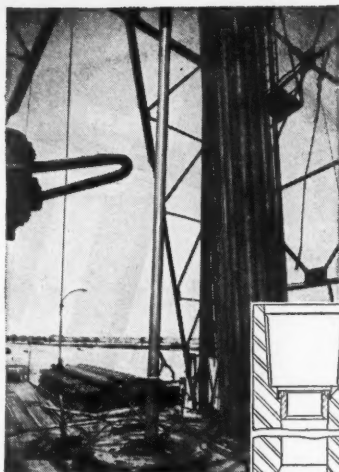
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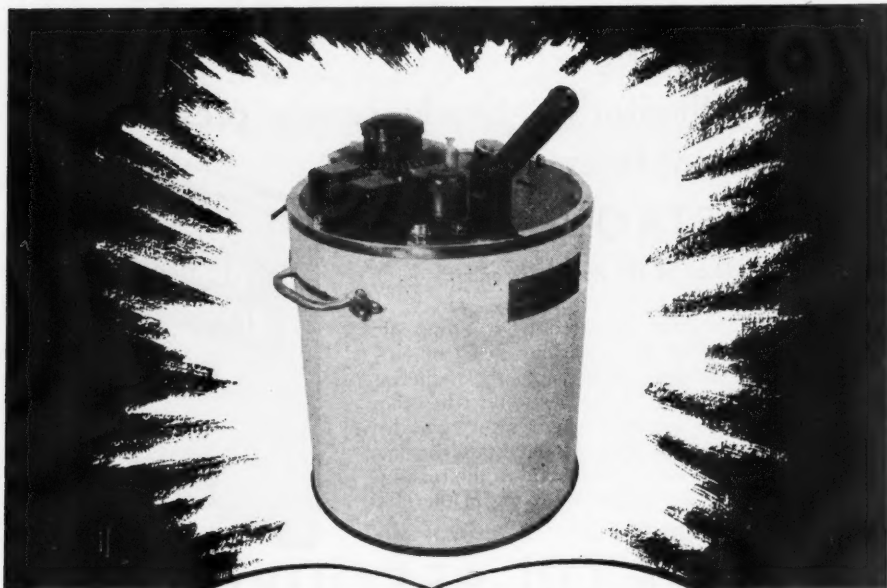
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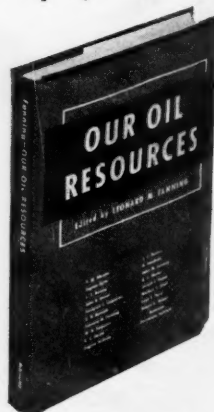
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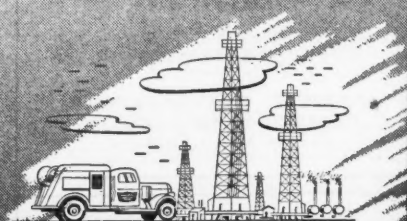
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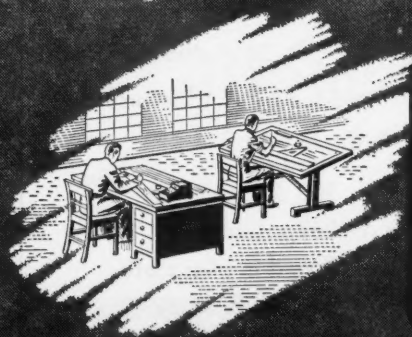
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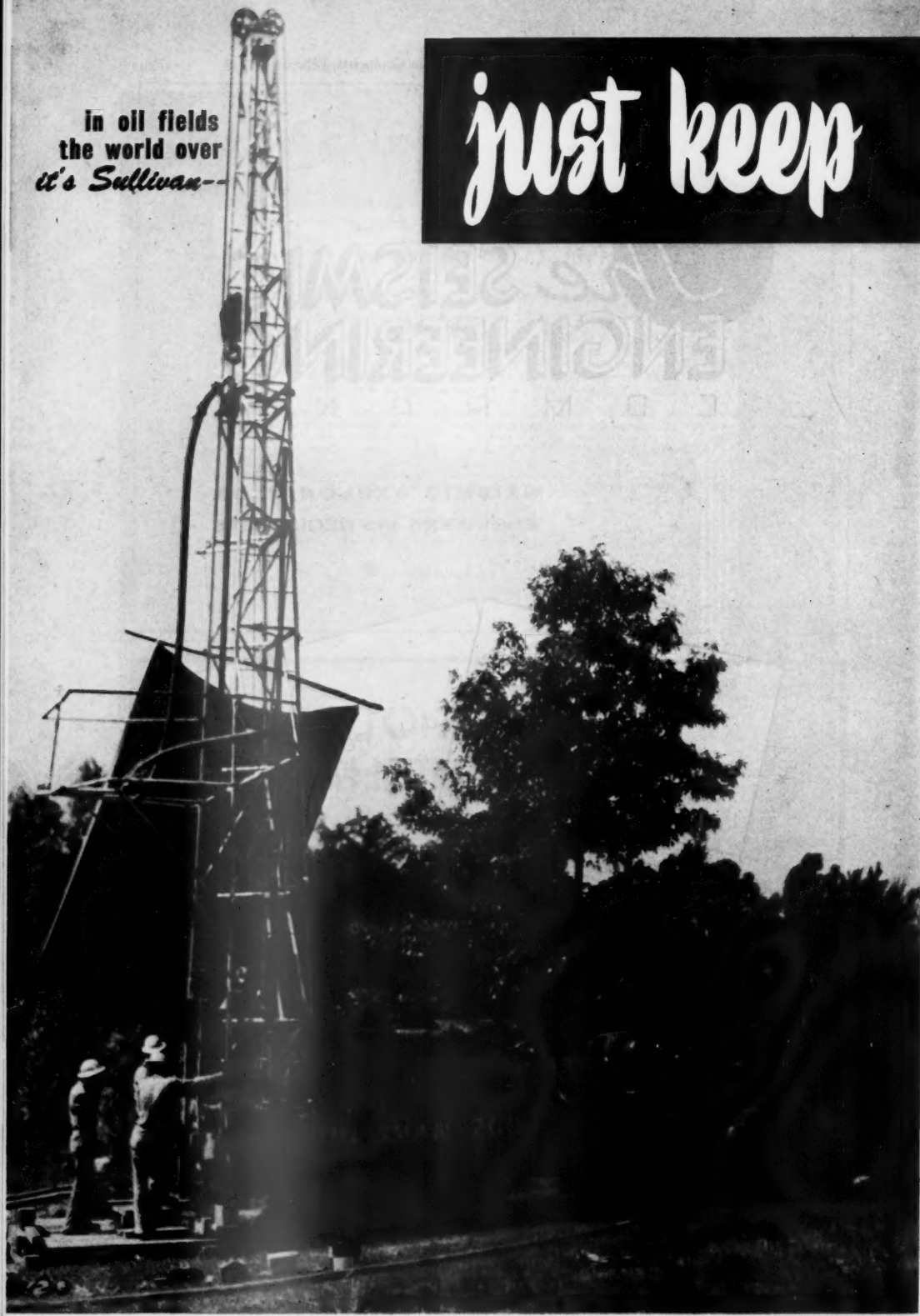
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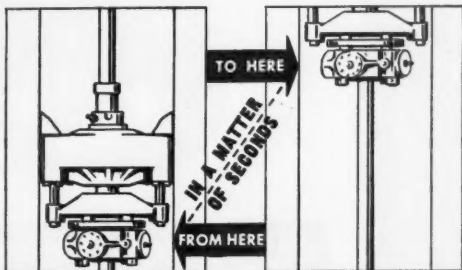
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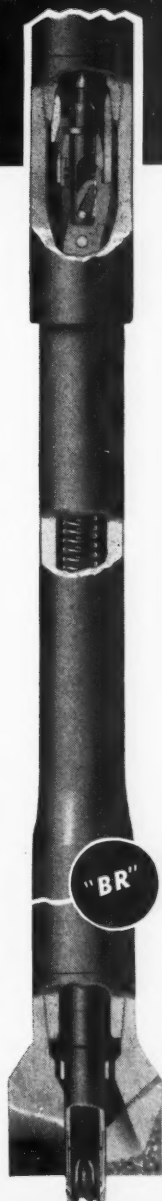
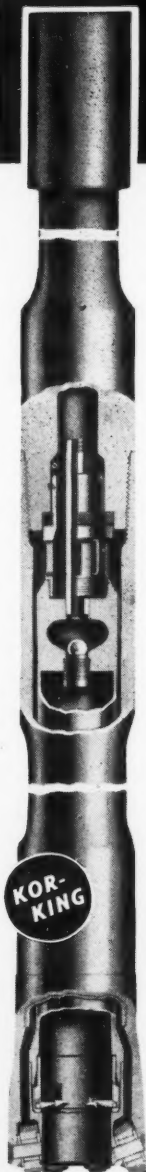
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